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REPORT OF AN INVESTIGATION OF DIRECT RECIRCULATION ON A HIGH-RATE TRICKLING FILTER, WEBSTER CITY, IOWA

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Environmental Health Center
Cincinnati, Ohio

1951

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REPORT OF AN INVESTIGATION OF DIRECT RECIRCULATION ON A HIGH-RATE TRICKLING FILTER

Webster City, Iowa

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With

Biological Report

By

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U. S. PUBLIC HEALTH SERVICE

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1. Summary and Conclusions

A study was made at the Webster City, Iowa, sewage treatment plant of the comparative efficiency of two high-rate trickling filters, one recirculating final effluent to the filter influent and the other recirculating filter effluent to the filter influent.

The two filters and their respective final settling tanks were identical in size and the primary settling tank effluent was divided equally between the two secondary units so that they received equal loadings of settled sewage. The recirculation ratio of approximately 1:1 was practically the same for both filters. Test runs were made of the two units operating in parallel before filter recirculation was started, to show that the two filters were truly comparable and that any differences in efficiency that might be found would be attributable to the study variable and not to inherent characteristics of the filters. Sixteen 24-hour and sixteen 4-hour tests were made for comparison of the recirculation methods during two experimental periods of two weeks each, representing summer and winter operation. Detailed biological examinations were made of the growths on the filter stone to determine the type and prevalence of organisms present under the varying conditions of operation and the variations in the fauna and flora resulting from changing environmental conditions and methods of recirculation.

During the entire study, underflow from the final clarifiers was returned to the primary clarifier influent at a rate averaging from 12 to 15 per cent of the sewage flow. This was to prevent sludge accumulating in the final clarifiers and not for the purpose of providing recirculation to the filters.

At all times the filter loadings, both hydraulic and organic, were higher than those for standard trickling filters which are usually designed for daily average rates of sewage application of approximately 3 million gallons per acre per day and an organic loading of about 0.2 pounds of 5-day B.O.D. per cubic yard of stone. The effluent quality obtained should not be compared with that which might be expected from standard rate filters. The loads on the filters with secondary recirculation averaged 21 m.g.a.d. and 1.4 lbs. of 5-day B.O.D. per cubic yard.

After secondary recurlation to the filter influents was installed, the efficiencies of the filters increased and a noticeably better effluent was produced.

The results obtained during the preliminary period and the two study periods are summarized in the following table.

Tabular Summary of Results

Test period	1 Prel. Check		3 Warm Weather		4 Cold Weather	
Secondary unit	1	2	1	2	1	2
Secondary recirculation	None	None	Effluent	Direct	Effluent	Direct
Number of tests	6	6	9	9	8	8
Flow (mgd)						
Raw sewage	0.51		0.59		0.53	
Applied to filter	0.29		0.61	0.61	0.59	0.60
Recirculation ratio						
Underflow	0.14		0.12		0.15	
Other	0.00		0.96	0.98	0.91	0.95
Filter loading						
Million gallons/acre/day	10.0		21.4	21.5	20.6	20.9
Lbs. B.O.D./cu.yd./day	0.924		1.040	1.200	1.410	1.610
Temperature of filter						
Influent (°C)	15.9	15.9	18.6	18.5	9.4	10.4
B.O.D. Non-Acid Treated (ppm)						
Raw sewage	174		141		189	
Applied to filter	135		70	81	101	112
Final clarifier effluent	67	69	34	32	62	49
B.O.D. Acid Treated (ppm)						
Raw sewage	164		134		Not run	
Applied to filter	134		67	70	Not run	
Final clarifier effluent	59	61	27	24	Not run	
Suspended solids (ppm)						
Raw sewage	115		128		178	
Filter effluent	76	75	50	48	56	74
Final clarifier effluent	36	37	23	22	53	41
Final clarifier effluent (ppm)						
Nitrate N (NO_3)	0.15	0.24	0.24	0.66	0.35	1.34
Nitrite N (NO_2)	0.48	0.51	0.92	2.09	0.16	0.20
Efficiency of B.O.D. Removal (%)						
Primary process	17.3		23.1		10.3	
Secondary process	54.2	52.5	66.8	70.8	63.3	71.3
Complete plant	61.8	60.5	75.4	77.6	67.0	74.0

This study of high-rate trickling filters with recirculation of filter effluent to filter influent (direct recirculation) and with recirculation of final effluent to filter influent, leads to the following conclusions for the conditions prevailing at Webster City:

1. With direct recirculation, there was less tendency towards filter ponding, and biological growths in the top 18 inches of filter stone were improved.

2. The secondary treatment unit using direct recirculation had an efficiency, based on B.O.D. removal, equal to or slightly greater than the unit with final effluent recirculation.

3. Direct recirculation produced slightly greater nitrification than did recirculation of final effluent. This increase was of no practical significance, but serves to corroborate the finding of slightly increased efficiency.

4. With average settled sewage loadings to the secondary treatment unit of 10 million gallons per acre of filter surface per day and 0.9 pound of 5-day, 20°C. B.O.D. per cubic yard of filter stone per day, a high-rate filter with direct recirculation of 0.9 to 1 and final settling can remove about 70 per cent of the biochemical oxygen demand and produce an effluent (from normal community sewage) with about 40 p.p.m. B.O.D. These secondary unit loadings of settled sewage were equivalent to actual filter loadings, including all recirculation, of 21.2 m.g.a.d. and 1.4 lbs. B.O.D./cu.yd/day.

2. Introduction

A. Statement of Problem

Recirculation of filter effluent direct to the filter influent has been proposed as one method of operation for high-rate trickling filters. Claims are made that this return of active biological material increases the efficiency of the filter and leads to a reduced capital cost of the plant because neither the primary nor secondary settling tanks need be designed to handle flow volumes in excess of the raw sewage.

Very little data have been available to judge the suitability of the process for particular installations and the efficiency of this method of recirculation in comparison with other methods more commonly used.

The Great Lakes and Upper Mississippi River Boards of State Sanitary Engineers requested the Public Health Service to undertake a study of the effect of direct recirculation on high-rate filters. The ultimate objective of the study was to provide the essential information upon which to base the review of proposed plants using this type of secondary recirculation.

Following a survey of various high-rate filter plants with recirculated flows that were being operated in the interested states, the Webster City, Iowa, plant was selected for this study, primarily because it has two identical secondary units consisting of high-rate filters and secondary clarifiers that could be readily adapted to the desired recirculation and placed in parallel operation. Field work on the study started on May 10, 1950, and was completed on December 13, 1950.

The study was divided into four parts, or periods of operation:

(1) Comparison of the efficiency of treatment by the two secondary units under normal parallel operation.

(2) The study of changing conditions caused by the installation of secondary unit recirculation.

(3) A test period; a comparison, during warm weather, of the relative efficiency of treatment by a secondary unit using direct recirculation and one recirculating settled filter effluent.

(4) Test period; a similar comparison of the efficiency of treatment by the two methods of secondary recirculation under cold weather conditions.

Biological investigations of the filters were made during the various operational periods of the study.

B. Organization

The study was made by the Environmental Health Center of the Public Health Service with the co-operation of the Iowa Department of Health, the city of Webster City, and Infilco, Incorporated, owners of the process patent.

Infilco, Inc., installed four additional arms on each filter distributor to accommodate the increased flows with recirculation, and provided pumping equipment, piping and flow measurement devices for the recirculation flows.

The City of Webster City provided the site, and all necessary utilities for operation of the mobile laboratories, and co-operated to the fullest possible extent in the conduct of the study. Mr. Leo Holtkamp, Superintendent of Sewage Treatment, was unsparing in his efforts to make the study a success, and was most helpful in making the necessary mechanical and operational changes.

The Iowa Department of Health collaborated in the entire study, making all the necessary local arrangements, providing continued advice and, during the cold weather test period, provided an assistant engineer and two sample collectors.

The Environmental Health Center, Public Health Service, provided the use of a mobile laboratory with its personnel, an engineer for field supervision of the project, part-time service of a biologist for the biological study, and two sample collectors for the spring and summer, engineering supervision for the entire project, and undertook the writing and reproduction of the project report.

Field personnel assigned to the project, and their sponsoring organizations, are listed below. Because of transfers and other commitments of the Environmental Health Center, a completely different field organization was used during the cold weather test period.

Public Health Service

Sanitary Engineer Graham Walton	May 8 to Nov. 25 (part time)
Biologist John Wilson	May 8 to Nov. 25 (part time)
J.A. Sanitary Engineer John Miner	May 8 to July 26
Chemist Jesse Cohen	May 8 to Aug. 1
Physical Science Aide John Kopp	May 8 to Aug. 1
Chauffeur-Mechanic Forrest Neal	May 8 to Aug. 1
Public Health Engineer Russell S. Smith	Nov. 21 to Dec. 7
Chemist Robert Kroner	Nov. 20 to Dec. 13
Physical Science Aide Richard Haggee	Nov. 20 to Dec. 13

Iowa State Department of Health

Assistant Engineer James Kimm	Nov. 22 to Dec. 7.

3. Plant Description and Engineering Data

A. General Description

Webster City, Iowa, has a population of 7609, according to the preliminary population figures from the 1950 census. It is located in the heart of one of the richest farming areas of the Midwest. The city has a system of combined sewers with an overflow weir by-pass above the treatment plant. In time of storm, the flow in the sewer system increases to several times the hydraulic capacity of the treatment plant, and this weir automatically by-passes the excess flow to the Boone River.

There are two major industries in the community, the Bean Manufacturing Company, which makes washing machines, and the Fairmont Poultry Packing Plant. There are two milk pasteurization plants, one of which also manufactures ice cream and processes a substantial amount of cream daily. Despite these industries, the sewage from the community is typical of a moderately strong domestic sewage, except for high hydrogen ion concentration which may be due to the lime softening of the city water supply.

The sewage treatment plant is located about one mile southeast of town and the effluent discharges into the Boone River. The plant, as designed, consisted of two comminutors with an inclined, manually cleaned bar screen for emergency use, a combination mechanical flocculator and a grit pocket, a grit washer, a circular clarifier equipped with a mechanical sludge-collecting and automatic skimming mechanism, two circular high-rate trickling filters, and two circular secondary clarifiers equipped with sludge-collecting and skimming mechanisms. A circular sludge digestion tank with floating cover and equipped for gas collection and heating was provided. There were eight open sludge - drying beds for air-drying the digested sludge.

The plant was designed to operate as a two-stage trickling filter plant with recirculation of 300 g.p.m. of underflow from the secondary clarifiers to the plant influent when flow rates were under 500 g.p.m., and as a single stage filter plant with the two secondary units in parallel, and the same recirculation for flow rates of 500 to 1200 g.p.m. When the flow rate was in excess of 1200 g.p.m., the valve on the inlet sewer would automatically close and the plant would be by-passed.

Under two-stage operation at low flows, the sewage entered the plant through a 24" cast iron pipe, flowed through the comminutors to the flocculator and grit pocket, and then through a Venturi meter into wet well #1. The sewage was pumped from this wet well to the primary

clarifier by three nonclog, horizontal, centrifugal pumps with rated capacities of 300, 400, and 500 gallons per minute respectively. These pumps were automatically controlled by means of a programmed float switch, provision being made for manual control if desired.

From the primary clarifier, the settled sewage, together with the recirculation flow, flowed by gravity to filter #1, to secondary clarifier #1 (intermediate clarifier), and to wet well #2. From this wet well, it was pumped to filter #2 by float controlled pumps identical to those at wet well #1. The filter effluent flowed by gravity to secondary clarifier #2, from which the plant effluent passed to the river.

When the incoming sewage flow exceeded 500 g.p.m., an electrically operated valve in a line from the primary clarifier to filter #2 opened, and a similar valve in the line from the intermediate clarifier to wet well #2 closed, so that the flow from the primary clarifier was divided between the two secondary units.

Sludge from the primary clarifier was pumped to the digester. Provisions were made for circulating the sludge in the digester through an external heat exchanger with heat supplied from a hot water boiler fired with digester gas. An overflow line for digester supernatant was provided to wet well #1, but the supernatant was customarily discharged to one of the sludge-drying beds through an improvised line.

B. Plant Units

Pumps - All pumps listed below, except the single cylinder, plunger-type sludge pump, are Chicago Pump Company horizontal, nonclog, centrifugal sewage pumps.

Pump No.	Rated Max. Speed r.p.m.	Dated Dynamic Head, ft.	Rated Capacity g.p.m.	Position or Duty
1	1150	35	300	Wet well #1
2	1150	27	300	Wet well #2
3	1150	32	400	Wet well #1
4	1150	24	400	Wet well #2
5	850	34	500	Wet well #1
6	850	25	500	Wet well #2
9	1150	21	300	Sec. Clar. sludge
10	1150	21	300	Sec. Clar. sludge
11	----	30	75	Pri. Clar. sludge

Pump #12 - Single cylinder plunger pump, max. speed 50 strokes/min. stroke adjustable from 0" to 5", capacity 75 g.p.m., total head 30'.

Screen - Two Chicago Pump Co. 15" comminuters, capacity 1.25 m.g.d., max. head loss 12".

Bar screen (emergency use) manually cleaned, 24-1/2" wide, 41" long, with 17 half-inch bars 1-1/2" on centers (16 openings 1" wide).

Flocculator and Grit Chamber, including Grit Pump and Grit Washer - The grit chamber is approximately 13' by 13' by 2' deep. The grit pump, grit washer, and flocculator were dismantled at the time of this survey, and no specifications are available for them.

Venturi Meter - One 7-1/2" x 20" flat invert type Venturi meter, manufactured by Builders Iron Foundry, Providence, R.I., installed in line from grit chamber to wet well #1, with a flow measurement range from 0.2 m.g.d. to 2.5 m.g.d. Attached to this Venturi meter is a combination flow-recording and totalizing mechanism, with electrical transmission of differential heads from floats in float tubes.

Wet Well #1 - The well is 22-3/4' x 6' x 8' deep. Pumps 1, 3, and 5 are connected to this wet well, and are operated in various combinations and stages by a programmed float control switch.

Primary Clarifier - An elevated circular clarifier, 40' in diameter, side water depth 9.1', with external effluent trough or launder. Surface area 1256 sq.ft., volume 85,500 gal. It is equipped with Dorrco Sifeed Torq clarifier and automatic skimmer.

Filter #1 - A circular filter 40' in diameter, with filter media approximately 7-1/2' deep. In the center is a concrete distributor base approximately 4' in diameter. The media is crushed granite supposedly in accordance with the following specifications:

"The stone shall be crushed quartzite, granite trap rock, dolomite, or limestone conforming to the following requirements:

Size -	Passing 3-1/2" screen	100%
	Retained on 3" screen	0-5%
	Retained on 2-1/2" screen	50%
	Passing 1-1/2" screen	0-3%
	Passing 1" screen	0%

"Soundness - (Sodium sulfate test)

Number of cycles	20
Material retained on 1" screen at end of test	85%
Material retained on 1/2" screen at end of test	95%

The method of test shall follow the report of the Iowa Engineers Committee on Filter Materials."

It is understood that the rock was graded before shipment, and that no particular care was used in handling or placement. Some large stones, probably in excess of 3-1/2", were noted on the filter surface. It is believed that the above specifications are only approximate. The filter area, or stone bed area, is 1244 sq. ft., or 1/35 acre, and the stone volume is 346 cu. yds.

The distributor is an eight-armed, orifice-and-splash plate, reaction-driven unit manufactured by Dorrco. It is provided with a mercury-filled seal chamber.

Secondary Clarifier #1 - A circular clarifier, 32' in diameter, with internal launder (29'-3" between weir crests), and side water depth of 8.6'. Area (net) 672' sq.ft. Volume 50,200 gallons. Equipped with Dorrco Sifeed Torq clarifier and automatic skimmer.

Wet Well #2 - Identical to Wet Well #1. Pumps 2, 4, and 6 are connected to this wet well.

Filter #2 - Identical to Filter #1, except visual observation indicates that surface rock is somewhat smaller than on Filter #1.

Secondary Clarifier #2 - Identical to secondary clarifier #1.

Sludge Digester - One 35' diameter sludge digester equipped with floating cover. The digester is provided with sludge circulating pump, heat exchanger, and a Pacific Flush Tank waste gas burner. A dual (gas and oil) fired boiler in the control house provides hot water for digester and plant heating.

Sludge-Drying Beds - Eight sludge-drying beds 25' x 50' long, area 1250 sq. ft. per bed, equipped with sand bottoms and underdrains.

Summary of Clarifier Characteristics
Under Average Conditions of Test Periods

Characteristic	Test Period		
	1 No Secondary Recirculation	3 Warm Weather, Sec. Recirc.	4 Cold Weather, Sec. Recirc.
Primary Clarifier			
Detention Period hours	3.5	3.1	3.4
Surface Settling Rate gals/sq.ft/day	720.	830.	770.
Weir Overflow R ate gals/lin.ft/min	3.2	3.7	3.4
Final Clarifier No. 1			
Detention Period hours	4.2	2.0	2.1
Surface Settling Rate gals/sq.ft/day	430.	910.	870.
Weir Overflow Rate gals/lin.ft/min	2.2	4.6	4.4
Final Clarifier No. 2			
Detention Period hours	4.2	3.7	4.0
Surface Settling Rate gals/sq.ft/day	430.	490.	450.
Weir Overflow R ate gals/lin.ft/min	2.2	2.5	2.3

Fig. 1-A. Primary Clarifier

Fig. 1-B. Filter & Secondary Clarifier

Fig. 1-C. Secondary Clarifier

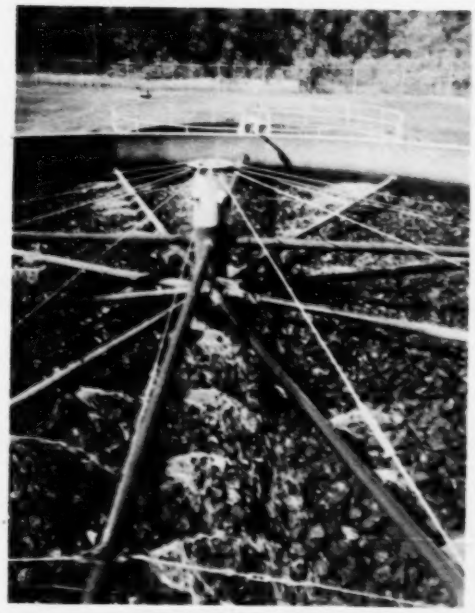

Fig.1-D.Distributor with Auxiliary Arms

Fig. 1 - Plant Units

4. Plant Operation During Study

A. Period 1 - Normal Parallel Operation (No recirculation to filters)

When the field crew arrived at the plant on May 10, 1950, the plant was being held in parallel operation for all rates of flow. This was accomplished by disconnecting the automatic controls, manually closing the valve from the intermediate clarifier to the wet well #2, and manually opening the valve from the primary clarifier to filter #2.

It was noted upon arrival at the plant that the mercury had been blown out of the distributor seal chambers, and that a substantial portion of the flow (est. 15-20%) was being lost at the base of the distributors. As repeated experience had indicated that it was not possible to keep mercury in the seal chamber during periods of high flow, a substitute had to be devised. The distributors were jacked up from the bases, and sponge rubber strips (such as that used in weather-stripping automobile doors) were cemented in place (with high tensile strength rubber gasket cement) in the grooves in the bases of the distributors. The distributors were then let down on the bases. The gaskets proved surprisingly effective and losses at the bases of the distributors were negligible after they were installed on May 12, 1950. They were still effective when the survey was concluded on December 8, 1950.

Another problem was presented when it was discovered that the distributors on the filters were not turning continuously during periods of low flow. It was also noted that the amount of raw sewage entering the plant was less than normally would be expected. Investigation of this latter circumstance led to the discovery that the main sewer line was partially clogged with grit about three-quarters of a mile from the plant, and that this was causing the sewage to overflow at the by-pass weir, which was located about 100 yards upstream from the clogged section. An estimated 30 to 40 per cent of the raw sewage was going over this weir directly to the river. City officials were contacted and requested to have the line cleaned out. When this was accomplished, the raw sewage flow at the plant increased approximately 35 per cent, and the filter distributors turned continuously except during periods of extremely low flow which usually occurred from 2:00 A.M. to 6:00 A.M. Frequent checks of the by-pass weir indicated that no sewage was being discharged to the river except during periods of storm water runoff.

In order to insure equal division of flow between the two secondary treatment units, a brass plate having two identical 16" rectangular weirs cut in it was installed in the channel leading from the primary clarifier effluent launder.

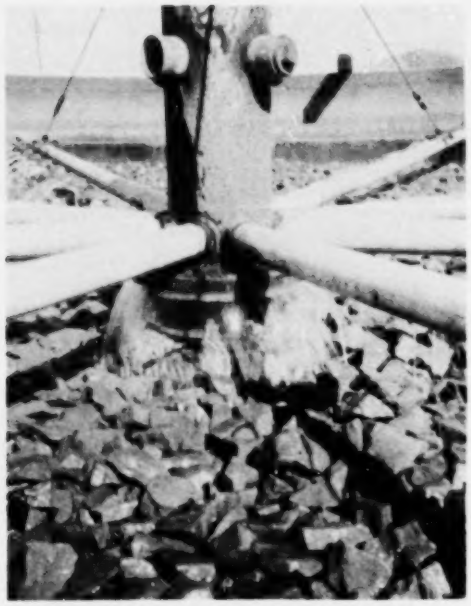

Fig. 2-A. Distributor base before installation of sponge rubber seal

Fig. 2-B. Installation of rubber seal

Fig. 2-C. Distributor base after installation of rubber seal

Fig. 2. Effect of Sponge Rubber Distributor Seal

After this preliminary work had been completed, Period 1 of the study commenced on May 18, 1950, and continued through June 6, 1950. Parallel operation of the two secondary units was maintained throughout this period. Reasonably equal flow division to the two units was assured by the weir plate in the primary clarifier effluent launder. Continuous recirculation from the two secondary clarifiers was maintained by pump #10 (pump #9 was not operated during the entire survey), which was calibrated at 120 g.p.m.* just before Period 1 began. Sludge was pumped from the primary clarifier to the digester 15 minutes every morning and evening. Actually, as far as plant operating procedures were concerned, Period 1 was exactly the same as normal operation for flows exceeding 500 g.p.m.

B. Period 2 - Adjustment to Secondary Recirculation

After the results obtained in Period 1 had shown that the two secondary units gave comparable treatment, two major changes were made in operating procedure to obtain the desired secondary recirculations for the rest of the study:

(1) Settled filter effluent (final effluent) was recirculated from secondary clarifier #1 to filter #1 influent at the rate of approximately 200 g.p.m., and unsettled filter effluent was recirculated directly back to filter influent at the rate of approximately 200 g.p.m. on filter #2.

(2) The pump (pump #10) for recirculating the underflow from the two secondary clarifiers was cleaned and connected to a time clock so that it would pump five minutes every half-hour. Recalibrations of the pump after cleaning showed a delivery of 290 g.p.m. Under these conditions, 69,600 gallons were pumped from the two secondary clarifiers during a 24-hour period. It was felt that this would provide adequate sludge removal from each secondary clarifier.

In order to obtain recirculation of filter effluent to filter influent on filter #2, pump #2 was removed from wet well #2**, and placed in the filter underdrain gallery of filter #2. A suction hose was run from the effluent channel in this underdrain gallery to the pump. The discharge line from the pump was connected to the 3" drain

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* This calibration of 120 g.p.m. on pump #10 did not hold long, since it was noted that recirculation began dropping off almost immediately. It was later discovered that the impeller of the pump had become partially fouled. The pump was dismantled and cleaned on June 8.

** Since plant was in parallel operation, sewage did not flow to wet well #2, and pumps on this wet well were not in use.

line that ran from the base of the distributor column to the underdrain gallery. An orifice meter with a mercury-filled, well-type manometer reading in gallons per minute, and a 3" gate valve were placed in the discharge line. With the gate valve wide open, a recirculation of about 210 g.p.m. was obtained. The valve was closed until a reading of 200 g.p.m. was obtained on the manometer. This recirculation rate of approximately 200 g.p.m. was held throughout experimental period 2.

Extreme difficulty was encountered in obtaining the desired recirculation flow rate on secondary unit #1. Various pumping arrangements were tried with the pumps available. Pump #6 from wet well #2 was used to pump from the outlet well of the secondary clarifier to the drain line of the filter distributor. The pump was installed at ground level and later mounted on a frame in the outlet box, but without success (Figure 3). Then a wooden platform was constructed and placed in the secondary clarifier with one side resting on the scum baffle, and the other side on two legs standing in the effluent launder. A sleeve was placed in the vertical outlet pipe of the launder to increase the water depth in this trough to 8" to serve as a pump suction well. Pump #4, from wet well #2, was mounted on this platform, and piping installed to discharge into a stock tank on the ground beside the clarifier. Pump #6 was arranged to take suction from this tank and deliver to the distributor drain line (see Figs 4 and 5). The desired recirculation rate could not be obtained by this two-stage arrangement, so the discharge from pump #4 was connected directly into the suction of pump #6 to utilize the full head available from both pumps (see Fig. 6). With this arrangement, a recirculation flow of 200 g.p.m. was obtained with the 3" discharge valve wide open.

To accommodate the increased hydraulic flow through the filters, four additional arms were added to each distributor approximately two feet above the original arms.

The second period was started on June 7, 1950, after the desired recirculation flow rates had been obtained, and analysis of the results obtained during the first period of normal parallel operation showed that the two secondary units were giving approximately equal treatment. This period was continued until July 10, when analysis of the data indicated that the filters had apparently reached a state of equilibrium after the change in operating conditions.

This adjustment period was considerably longer than is usually considered necessary for trickling filters. This may be attributed to the fact that many heavy rains occurred during the month, and that, in consequence, the sewage was very weak. Furthermore, on several days the storm runoff caused the Boone River to reach a stage that necessitated closing the inlet valve to the plant. This intermittent operation continued through June 26, and high flows of weak sewage (due to infiltration from wet soils) persisted to the last of the period.

Fig. 3. Pump in outlet box. Line from pump discharge to filter effluent (secondary unit #1)

Fig. 4. Two-stage pumping arrangement showing stock tank and 500 gpm. pump

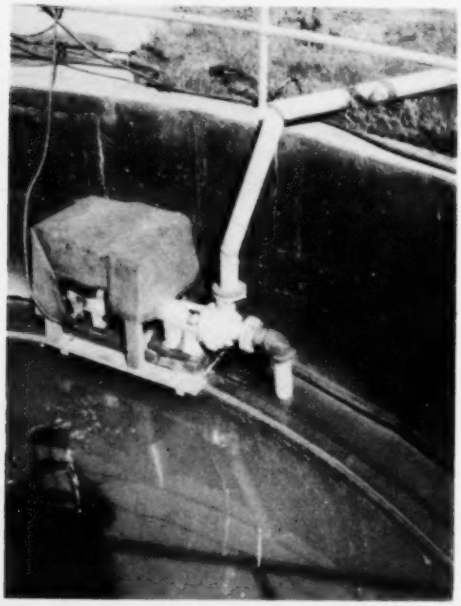


Fig. 5. 400 gpm. pump mounted down in secondary clarifier #1. Platform resting on scum baffle.

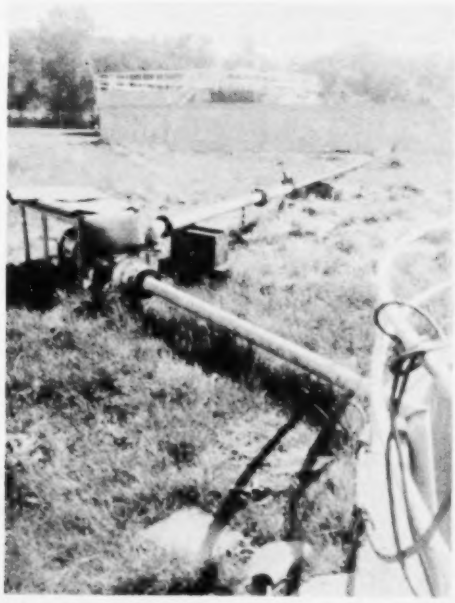


Fig. 6. 500 gpm. pump connected directly to 400 gpm. pump down in secondary clarifier # 1.

C. Periods 3 and 4. Test Periods for Comparison of Recirculation Methods

No changes in plant operation were made after the end of the second period. These two periods provided the data for the primary purpose of the study, which was the comparison under warm and cold weather conditions of the efficiencies of the two methods of recirculation to the filters. All work in the first two periods was preliminary to these two test periods.

The third period (warm weather conditions) followed immediately after the adjustment period and extended through July 26.

The fourth period (cold weather) was from November 27 to December 9. The first day of this period a sample jar was lost in secondary clarifier #1, and could not be immediately recovered. For this reason, the clarifier mechanism was shut down and underflow recirculation from this tank was stopped. All underflow recirculation for the first week of the period was from secondary clarifier #2. Probably due to the low prevailing temperatures, no trouble was experienced from sludge turning septic and rising. After the first week's operation, the clarifier was drained, the sampling jar recovered, and the plant restored to desired operating conditions.

During the fourth period, the underflow recirculation pump was recalibrated and found to be delivering 292 g.p.m., or 421,000 g.p.d. The pump operation cycle was timed, and it was determined that the pump operated 608 seconds in 3602 seconds, or 16.9 per cent of the time, giving a computed recirculation of 0.071 m.g.d.

5. Hydrometric Data

A. Flow Measurements

The only flow-measuring device provided in the plant was the 7-1/2" x 20" flat invert Venturi meter located between the grit chamber and wet well #1. The approach and throat heads from this meter tube were transmitted to open float tubes and mechanically to a differential cam on an electrical transmitting device. The differential head was transmitted to an indicating, recording, and integrating mechanism on the main switchboard. It was found that the transmission device was very difficult to adjust properly, and that the setting was not permanent over a period of weeks.

Calibration curves for the meter tube were obtained from the meter manufacturer. A differential U-tube gauge with 40" legs of 1/2" glass tubing and scale reading in inches and tenths was installed on the Venturi meter. This U-tube gauge was filled with colored carbon disulfide to magnify the differential readings and increase the accuracy at times of low flow when the differential would have been less than one inch of water. It was intended to use this differential gauge primarily as a check on the regular recording instrument, but it was found more advantageous to use the Venturi tube and differential gauge as the primary flow-measuring device with readings made every half hour during sampling periods.

Flow measurements of the underflow recirculation were obtained from calibration of the pump discharge and time of operation. Calibration of discharge was made by noting the time intervals for filling successive tenths of a foot of the primary clarifier, or similar drawdown of secondary clarifiers, using a hook gage for water level readings and a wrist watch for timing. The pump was calibrated in this manner on three occasions. On the first calibration just previous to the start of period 1, the flow was 120 g.p.m. On June 8, the pump was dismantled and the impeller was found to be partially clogged. On June 12, the pump was calibrated again, and the flow was 290 g.p.m. The last calibration was during the fourth test period in December, and the flow was 292 g.p.m.

As previously stated, a double weir plate was installed in the primary clarifier effluent channel to insure equal flow division to the two filters. A continuously recording water level gauge and a hook gauge were installed to obtain head and discharge records for these weirs. It was presumed that these weirs would provide accurate measurements of the flow of settled sewage plus underflow recirculation to each of the filters, and so provide a reliable measure of this recirculation. However, due to float control of the sewage pumps which, at times, operated on a cycle of less than a minute, and to the intermittent

operation of the recirculation pump after the first period, there were very rapid fluctuations of large magnitude in the rate of flow through the various plant units. These rapid fluctuations in head on these weirs made the computed flows very inaccurate, and the measurements were not used for this report. These head readings were not taken during the final period.

Metal sleeves were caulked into the outlet of each final effluent line, and orifice plates with 6" diameter orifice holes concentric with the pipe were bolted to these sleeves. A piece of 1/4" pipe, 18" long, capped on the end, and perforated with 1/16" holes, coupled to a nipple welded into the plate below the orifice, extended into the sewer. The exposed end of the nipple was connected to a stilling well provided with a hook gauge to measure hydrostatic heads. These orifices would perform as circular weirs at heads (measured from center of orifice) between -0.25 ft. and + 0.25 ft and as circular orifices at heads in excess of + 0.25 ft. It was expected that these flow records would serve as an additional check on the equal distribution of flow to the two secondary units, and that the sum of the flows as determined by these orifices should serve as an additional check on the flows computed from the Venturi meter. Actually, the flow readings from these orifices were found to be very unsatisfactory, due to the rapidly fluctuating heads caused by surges through the plant, to the fact that much of the time the heads were in the critical range between weir and orifice conditions, and to clogging of the pressure lines to the stilling wells. The orifices and stilling wells were in a rather inaccessible location, being in two deep manholes. Use of these devices was abandoned within a short time.

Orifice meters with mercury, well-type manometers were installed in the filter recirculation lines of both secondary units. These meters, which were furnished by Infilco, Inc., read directly in gallons per minute. These flows were found to be very uniform. The manometers were, therefore, read at four-hour intervals to determine the average rate of flow over the 24-hour sampling periods.

These flow-measuring devices, except the final effluent orifices, are shown in Figs. 7 to 10. Flow rates for each of the 24-hour and 4-hour sampling periods have been computed. Summarization of the flow data for each period of the study, as well as for a combination of periods 3 and 4, is given in tables 1 and 2.

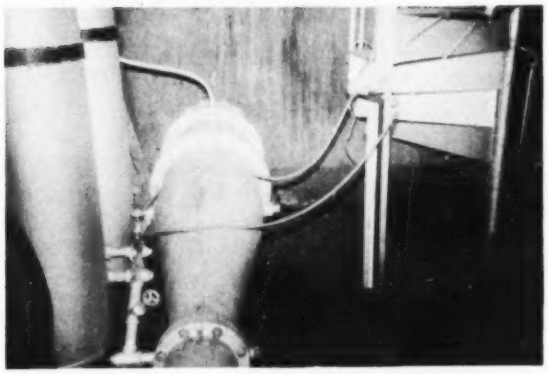


Fig. 7. Venturi meter and U-tube gage

Fig.8. Weir Plate showing hook gage & water level recorder

Fig.9. Reading hook gage

Fig.10. Orifice plate and manometer

Table 1 - Summary of Flow Data, 24-Hour Tests

	Raw Sewage Flow MGD	Primary Clarified Effluent MGD	Filter Influent, MGD		Dosing Rates MGAD		Recirculation Rates MGD			Temperatures		
			Unit 1	Unit 2	Unit 1	Unit 2	Primary Clarifier	Filter 1	Filter 2	Air °C. Daily Mean	Filter Influent °C. 1	Filter Influent °C. 2
	May 18 - June 6 (6)*				Period 1 - Normal Parallel Operation for Base Comparison							
Average	0.51	0.57	0.29	0.29	10.0	10.0	0.14	0.0	0.0	17.8	15.9	15.9
Maximum	0.59	0.66	0.33	0.33	11.6	11.6	0.37			22.2	17.6	17.6
Minimum	0.41	0.46	0.23	0.23	8.0	8.0	0.06			15.6	15.2	15.1
	June 9 - July 7 (9)				Period 2 - Adjustment of Secondary Units to Recirculation							
Average	0.69	0.84	0.69	0.71	24.0	24.9	0.23	0.76	0.84	20.0	17.5	17.4
Maximum	0.78	1.05	0.73	0.81	25.4	28.4	0.73	0.88	0.99	25.6	19.9	19.3
Minimum	0.60	0.72	0.64	0.64	22.4	22.5	0.09	0.50	0.74	16.7	16.4	16.1
	July 10-26 (9)				Period 3 - Test Period, Warm Weather							
Average	0.59	0.66	0.61	0.61	21.4	21.5	0.12	0.96	0.98	21.1	18.6	18.5
Maximum	0.65	0.72	0.64	0.64	22.4	22.5	0.14	1.07	1.11	24.4	19.2	19.0
Minimum	0.52	0.59	0.57	0.58	19.9	20.2	0.11	0.87	0.88	15.6	17.3	17.3
	Nov. 28 - Dec. 7 (7)				Period 4 - Test Period, Cold Weather							
Average	0.53	0.61	0.58	0.59	20.4	20.9	0.15	1.08	1.12	-5.6	9.1	10.0
Maximum	0.60	0.69	0.62	0.67	21.8	23.4	0.20	1.22	1.24	0.0	11.3	12.1
Minimum	0.46	0.55	0.55	0.56	19.4	19.6	0.12	0.96	0.97	-15.6	6.0	6.8
	July 10 - Dec. 7 (16)				Periods 3 and 4 - Both Warm and Cold Weather Test Periods							
Average	0.56	0.64	0.60	0.60	20.9	21.2	0.14	1.01	1.04			
Maximum	0.65	0.72	0.64	0.67	22.4	23.4	0.20	1.22	1.24	24.4	19.2	19.0
Minimum	0.46	0.55	0.55	0.56	19.4	19.6	0.11	0.87	0.88	-15.6	6.0	6.8

* Figure in parentheses indicates number of tests run in group.

Table 2 - Summary of Flow Data, 4-Hour Tests

	Raw Sewage Flow MGD	Primary Clarifier Effluent MGD	Filter Influent, MGD		Dosing Rates MGAD		Recirculation Ratios		
			Unit 1	Unit 2	Unit 1	Unit 2	Primary Clarifier	Filter 1	Filter 2
May 22 - June 6 (7)*			Period 1 - Normal Parallel Operation						
Average	0.66	0.72	0.36	0.36	12.6	12.6	0.09	0.00	0.00
Maximum	0.75	0.89	0.44	0.44	15.5	15.5	0.18		
Minimum	0.42	0.45	0.23	0.23	8.0	8.0	0.04		
June 9 - July 7 (9)			Period 2 - Adjustment of Secondary Recirculation						
Average	0.80	0.96	0.74	0.77	25.9	26.8	0.19	0.65	0.72
Maximum	0.86	1.23	0.79	0.90	27.8	31.6	0.59	0.73	0.75
Minimum	0.73	0.84	0.70	0.70	24.6	24.6	0.08	0.38	0.69
July 10 - 26 (9)			Period 3 - Test Period, Warm Weather						
Average	0.74	0.81	0.69	0.69	24.1	24.2	0.10	0.76	0.77
Maximum	0.83	0.90	0.73	0.74	25.6	25.8	0.10	0.83	0.85
Minimum	0.68	0.74	0.65	0.66	22.8	23.0	0.08	0.68	0.69
Nov. 28 - Dec. 7 (7)			Period 4 - Test Period, Cold Weather						
Average	0.72	0.79	0.68	0.69	23.6	24.1	0.10	0.79	0.81
Maximum	0.84	0.91	0.74	0.76	25.8	26.4	0.14	0.90	0.93
Minimum	0.62	0.69	0.63	0.63	21.9	22.2	0.08	0.67	0.69
July 10-Dec.7(16)			Periods 3 & 4 - Both Cold and Warm Weather Test Periods						
Average	0.73	0.80	0.68	0.69	23.9	24.1	0.10	0.78	0.80
Maximum	0.84	0.91	0.74	0.76	25.8	26.4	0.14	0.90	0.93
Minimum	0.62	0.69	0.63	0.63	21.9	22.2	0.08	0.67	0.69

* Figure in parentheses indicates number of tests in group.

B. Filter Distribution Tests

Pan tests for sewage distribution on the two filters were made in July during the warm weather test period. Nine metal trays 10 inches wide by 24 inches long by 4 inches deep, divided into four water-tight compartments, each 6 inches by 10 inches in plan, were placed end to end in a shallow trench excavated in the filter stone along a radius of the filter. The pans were adjusted so that the top of the trays was approximately at the elevation of the stone surface. Fig. 11 shows the arrangement of the trays for a distribution test.

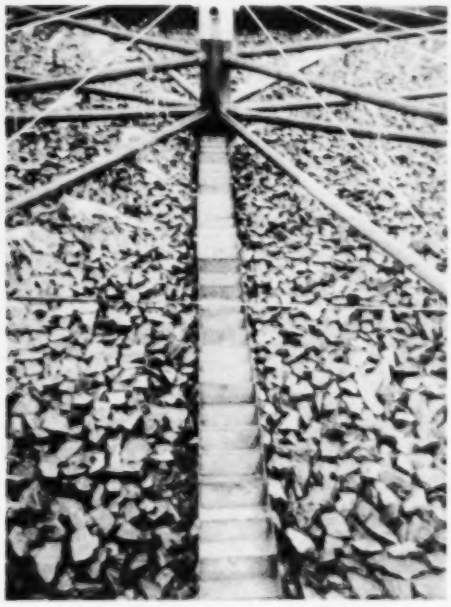


Fig. 11 - Arrangement of Trays for Filter Distribution Test.

For the test, the filter distributor was allowed to make eight revolutions, and then stopped at a point where no spray was discharged into the trays. The water depth in each section was measured to the nearest 1/8" at each end of the section with the trays in place, and the two readings were averaged to determine the depth of water in the section. These depths in the various sections represented the depths applied to the corresponding 6" concentric rings of filter surface.

From these results, distribution data, as suggested by Walton ("High Daily Rate Trickling Filter Performance," March, 1943, Upper Mississippi River Basin Board of State Health Commissioners), as well as the standard deviation and coefficient of variation according to standard statistical procedure, were computed and are tabulated in Table 3. The terms used in this table may be defined briefly as follows:

Coefficient of Area is a ratio of filter surface receiving sewage to the total filter area.

Coefficient of Distribution is an empirical evaluation of the uniformity of dosing by a single term. It is computed by adding the percentage of filter areas on which the flow deviation exceeds 100 per cent, 75 per cent, 50 per cent, 25 per cent, and 0 per cent, and dividing the sum by 100.

Dosing Ratio is the maximum depth applied to any unit area divided by the mean depth for all areas.

Table 3 - Filter Distribution Data

Data	Filter #1	Filter #2
Dosing Rate (m.g.a.d.)	24.2	24.3
Coefficient of Area	0.98	1.00
Coefficient of Distribution	1.47	1.36
Dosing Ratio	1.70	1.69
Mean Depth (1/16 inch) - M	31.76	36.07
Standard Deviation (1/16 inch) - SD	$\pm$ 9.87	$\pm$ 9.51
Coefficient of Variation ($\frac{SD}{M}$ x 100)	31.1 %	26.4 %

6. Collection, Compositing and Storage of Samples

A. Sample Points

Sample points were established so that the flows through the plant could be sampled at each point where the characteristics would be liable to change. The only flow that was not sampled was the underflow recirculation from the secondary clarifiers. This recirculation was in a closed pipe system, and there were no taps or open channel sections available for sample collection. Each sample point was assigned a number for record purposes, and a color identification to aid the sample collectors. Table 4 lists the various sample points, with their number and color designations.

Table 4. Sample Points and Identification Scheme

Sample Point	Identification	
	Number	Color
Raw Sewage	1	Black
Primary Clarifier Effluent	2	Brown
Filter No. 1 Influent	3	Red
" " 2 "	4	Yellow
" " 1 Effluent	5	Blue
" " 2 "	6	Orange
Secondary Clarifier No. 1 Effluent	7	Green
" " " 2 "	8	White

The raw sewage sample was taken between the bar screen and the Venturi meter and the primary clarifier effluent in the outlet box of the launder just ahead of the dividing weir. The filter influent samples were taken from an outer orifice of a distributor arm. Filter effluent samples were taken from the outlet of the underdrain collecting gutter, and final clarifier effluent samples were taken from the outlet of the launders.

B. Sampling Equipment

Included in sampling equipment are the items used for taking, transporting, and proportioning the individual sample portion and for storing and refrigerating the composite samples until they are taken into the laboratory.

For refrigeration of the composited samples, a top-opening, mechanically refrigerated beverage cooler was obtained. This cooler had a sectional hinged and removable top, and was so constructed that it could be used as either a wet or dry cooler. This unit had an advantage over the household type of refrigerator in that the sample containers did not have to be removed to add the individual portions. This eliminated labor, chance of spillage or breakage, and diminished the possibility of error.

The containers for the composited samples were 4-1/2 quart aluminum dressing jars. These were about 8 inches in diameter and 9 inches high, with a lid overlapping the sides. They were of such size that 16 of them fitted easily within the cooler, were nonbreakable, and were not corroded by the sewage. In addition, the large opening made it very easy to pour in the individual portions without removing the container from the cooler. The high thermal conductivity of these jars cooled the contents to the desired temperature much more quickly than would glass jugs or bottles. However, nine-quart cream cans of tinned iron were used for the raw sewage samples because of the larger volume of the composited sample. The lids and a portion of the sides of the containers were numbered and color-marked to correspond with the code designation of the various sample points. Solid color was used for the containers for 24-hour composite samples, and striped color for the containers for short-period composites. Fig. 12 shows the cooler with the hinged lid completely removed and the sample containers in place.

Fig. 12 - Sample Cooler and Containers

C. Sampling Methods

Samples were collected in pint Mason jars. At most sample points the jars were placed in a shallow metal cup attached to the end of a rod of proper length to allow easy submersion of the jar in the sewage flow. A ring of rubber tubing attached to the rod was stretched over the neck of the jar to hold it in the cup. An individual sampling rod was provided for each sample point. Each jar and rod was painted with the proper color to identify it with the sample point at which it was to be used. A stake or other marker was painted the proper color for the sampling point and firmly mounted at the point where the sample was to be taken. Sampling rods were not used in taking filter influent samples from the distributor arms. At first, the distributor was stopped and the sample taken by holding a jar in the stream from the outside orifice on one arm. Later a small tinned pail was set on the filter surface, allowed to fill, and then removed without stopping the distributor.

D. Collection and Compositing

Samples were collected and composited for 24 and 4-hour periods. The 24-hour period started at 7:00 A.M. on the sample date and ended at 6:30 A.M. the following day, except during the fourth study period when the sampling day was from 8:00 A.M. to 7:30 A.M. Samples of the raw sewage were taken every half hour, and all other points were sampled every hour. The individual portions for the composite were proportioned (to the nearest 5 ml.) in accordance with the raw sewage flow at the time of sampling, with allowance for the recirculation flow volumes at the different points. A table was prepared for the sample collectors, giving the volume of portion to be used at each sample point for the various differential gauge readings of the Venturi meter. On the 24-hour runs, the sample collecting periods were not staggered to allow for the detention periods in the various plant units.

When collecting the hourly samples, the sample collector started with the full set of sample jars in a metal milk bottle carrier. Upon arriving at a sample point, he made any necessary flow measurements, noted the color designation of the point from the marker, selected the jar of the corresponding color and took the sample. When he returned to the control building, where the cooler was located, one jar at a time was removed from the carrier, the sample thoroughly stirred, the required portion measured in a graduate and added to the aluminum container with the same color marking as the jar. The use of this color code for sample points greatly reduced the probability of error in compositing the samples. It also aided the laboratory personnel in identifying the samples when they were brought to the laboratory.

In addition to these 24-hour samples, 4-hour composite samples were taken to determine the effect of the daily heavy flow period on plant operation. The raw sewage sample was collected from 10:00 A.M. to 2:00 P.M. Through the rest of the plant, the detention time, based on daily average sewage flow between 10:00 and 2:00, was estimated for each plant unit, and the time of the sample period set accordingly.

Special grab samples were collected four times daily from all points except the two final effluents during the first three study periods. Dissolved oxygen, pH, and settleable solids (Imhoff cone) determinations were made on these samples. During the fourth period, similar grab samples were collected from all points, and determinations of dissolved oxygen and pH were made. The dissolved oxygen grab samples from shallow channels were collected by means of a special shallow-water D. O. sampler. This was a galvanized can, 8" in diameter and 4" high, with tight bottom and open top. A 1/8" pipe nipple was inserted through the side as near the bottom as possible, and soldered in place. The outer end of the nipple was inserted into an 18" piece of rubber tubing closed with a pinchcock. In taking the sample, the can was placed on the bottom of the channel and allowed to remain there a short time after filling, to allow the water to circulate through it. When it was removed from the channel, the end of the rubber tube was inserted into a D. O. bottle to the bottom, and the clamp released. The bottle was filled in the customary manner, allowing an overflow of two times the volume, the bottle stoppered, and the dissolved oxygen determination made.

Sample collection at the various sample points is shown in Figure 13.

Fig. 13-A. Raw Sewage

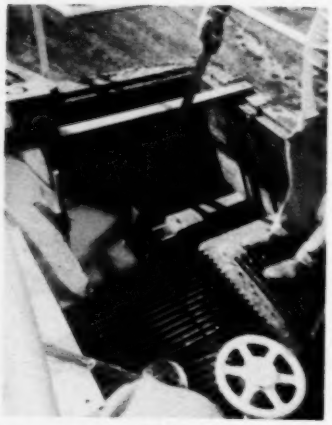


Fig.13-B.Primary Clarifier Effluent

Fig. 13-C. Filter Influent

Fig.13-D. Filter Effluent

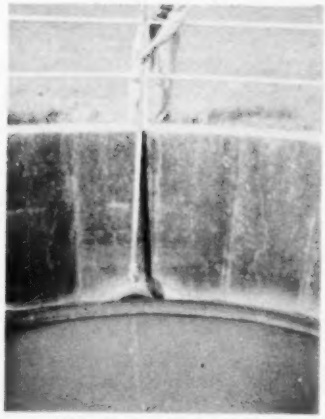


Fig.13-E. Final Effluent

Fig. 13. Sample Collection

7. Analytical Procedures

Suspended solids, biochemical oxygen demand, nitrogen, and hydrogen ion determinations were made on the composite samples. Total and fixed suspended solids were determined and the volatile suspended solids were obtained by subtraction. Biochemical oxygen demand determinations were made on both normal and acid-treated samples except in the last period, when the acid-treated samples were not used. Results are expressed as parts per million of 5-day biochemical oxygen demand at 20°C. (B.O.D. p.p.m.). Total Kjeldahl nitrogen and ammonia were determined and the organic nitrogen obtained by subtraction. Hydrogen ion determinations were made by use of a line operated, glass electrode instrument, except during the second week of the last period when colorimetric methods were used.

Settleable solids (by volume), hydrogen ion concentration (pH) (colorimetric), and dissolved oxygen determinations were made on the grab samples by the sample collectors under the supervision of the chemist.

In general, analyses were made in accordance with procedures given in "Standard Methods for the Examination of Water and Sewage, Ninth Edition (1946)." The acid-treated biochemical oxygen demand tests were made in accordance with a procedure outlined in "Nitrification and B.O.D.," Sewage Works Journal, November, 1947, p.996, and were intended to insure that only carbonaceous demand was being measured. The sodium azide modification of the Winkler method was used for all determinations of dissolved oxygen.

In the total Kjeldahl nitrogen determination, selenium (Hengar granules) was used as a catalyst instead of the copper sulfate specified in Standard Methods. Direct nesslerization was used to determine the ammonia nitrogen,and nitrate nitrogen was determined by the phenol disulfonic acid method.

8. Analytical Results

Twenty-four hour composite samples were collected and analyzed on 31 days, and four-hour composite samples were taken on 32 days. The averages, maximums, and minimums for the various periods of operation are summarized in tables in the body of this report. In the summary tables, the third and fourth periods have also been combined to show typical results of recirculation for both warm and cold weather.

The pH was determined on all composite samples, and no unusual fluctuations were observed. The pH of composited samples ranged between 9.0 and 7.3, which is above the range usually observed in sewage treatment plants. This high pH is probably attributable to the high pH of the city water supply, which is lime-softened.

B.O.D. Determinations

Summaries of the B.O.D. results by operation periods will be found in Table 5 for the 24-hour, and Table 6 for the 4-hour composites.

During the first three periods, B.O.D. determinations were made on both acid-treated (A.T.) and non-acid-treated (N.A.T.) samples to determine which method would give the better indications of plant operation for comparison of the secondary units. The differences in results by the two methods are summarized in Table 7. As was anticipated, there was little difference between N.A.T. and A.T. B.O.D. in the primary treatment process, because the nitrification of the sewage had not proceeded to an appreciable extent. The filter effluent samples showed a marked difference in the results in the B.O.D. determinations by the two methods, but this variation was not as pronounced in the final clarifier effluents. The differences in the results of N.A.T. and A.T. determinations of B.O.D. were not the same for the filter influents of the two units during recirculation; because Unit 1 reflects the lesser difference in final clarifier effluent, and Unit 2 reflects the greater difference in the filter effluent.

For comparison of the efficiencies of the two secondary processes, it apparently makes little difference which method of B.O.D. determination is used. Only for the 4-hour test in the second period, does the difference in per cent efficiency between the two processes, as determined by the efficiency ratio of A.T. to N.A.T. methods, amount to more than 3 per cent. In all other cases, the results differ by less than 1.5 per cent.

Because of the close correlation of the comparable efficiencies and to conserve laboratory man-hours and incubation space, acid-treated B.O.D. determinations were not made in the fourth period.

Table 5 - Summarized B. O. D. Results, 24-Hour Composite Samples

	B. O. D. (Nonacid-Treated) p.p.m.										B. O. D. (Acid-Treated) p.p.m.							
	Raw Sewage	Primary Clarifier Effluent	Filter Influent		Filter Effluent				Final Effluent		Raw Sewage	Primary Effluent	Filter Influent		Filter Effluent		Final Effluent	
					Non-settled		Settled											
			1	2	1	2	1	2	1	2			1	2	1	2	1	2
	May 18 - June 6 (6)* Period 1 - Normal Parallel Operation																	
Average	174	135	137	135	105	101			67	69	164	134	134	130	86	82	59	61
Maximum	194	158	163	156	139	141			86	86	195	159	164	158	107	101	79	81
Minimum	141	104	100	103	57	63			43	41	136	90	90	86	52	50	34	34
	June 9 - July 7 (9) Period 2 - Adjustment of Secondary Units to Recirculation																	
Average	128	85	64	73	65	73	26	30	35	39	116	80	59	63	41	47	27	30
Maximum	228	147	123	113	142	148	34	39	72	68	219	144	122	113	101	102	62	60
Minimum	61	50	37	32	28	21	17	18	14	16	57	44	31	31	17	20	12	16
	July 10 - 26 (9) Period 3 - Warm Weather Test Period																	
Average	141	101	70	81	57	53	33	32	34	32	134	96	67	70	40	35	27	24
Maximum	205	142	93	115	69	93	46	61	45	59	192	129	87	105	55	63	42	42
Minimum	71	46	41	39	40	30	21	18	22	15	62	43	36	28	22	14	12	9
	Nov. 28 - Dec. 7 (7) Period 4 - Cold Weather Test Period																	
Average	189	154	101	112					62	49								
Maximum	238	175	115	128					93	72								
Minimum	144	109	75	98					20	21								
	July 10 - Dec. 7 (16) Periods 3 and 4 - Both Warm and Cold Weather Test Periods																	
Average	162	124	84	93					46	39								
Maximum	238	175	115	128					93	72								
Minimum	71	46	41	39					20	21								

* Figure in parentheses indicates number of test runs in group.

Table 6 - Summarized B. O. D. Results, 4-Hour Composite Samples

	B. O. D. (Nonacid-Treated) p.p.m.								B. O. D. (Acid-Treated) p.p.m.							
	Raw Sewage	Primary Clarifier Effluent	Filter Influent		Filter Effluent		Final Effluent		Raw Sewage	Primary Clarifier Effluent	Filter Influent		Filter Effluent		Final Effluent	
			1	2	1	2	1	2			1	2	1	2	1	2
	May 22 - June 6 (7)* Period 1 - Normal Parallel Operation															
Average	298	201	200	206	160	153	91	93	284	198	194	197	138	133	85	87
Maximum	527	291	284	288	232	201	129	118	520	291	283	289	179	175	123	116
Minimum	207	172	178	183	109	109	74	77	193	160	160	160	92	92	68	67
	June 9 - July 7 (9) Period 2 - Adjustment of Secondary Units to Recirculation															
Average	195	118	91	105	88	90	43	50	191	116	89	94	58	67	37	40
Maximum	339	183	165	167	223	203	96	92	329	185	170	169	149	156	89	89
Minimum	112	64	50	53	33	24	17	21	105	67	51	52	26	27	15	20
	July 10-26 (9) Period 3 - Warm Weather Test Period															
Average	240	147	110	110	70	65	46	41	238	145	106	98	56	50	38	32
Maximum	427	220	162	174	99	127	83	83	423	222	160	157	97	109	70	69
Minimum	94	52	44	52	43	27	26	17	78	47	36	34	24	15	14	11
	Nov. 28 - Dec. 7 (7) Period 4 - Cold Weather Test Period															
Average	284	190	120	130			68	57								
Maximum	412	259	182	195			92	87								
Minimum	210	139	61	94			37	33								
	July 10 - Dec. 7 (16) Periods 3 and 4 - Both Warm and Cold Weather Test Periods															
Average	257	166	143	118			56	48								
Maximum	427	259	182	195			92	87								
Minimum	94	52	44	52			26	17								

* Figure in parentheses indicates number of tests in group.

Table 7 - Comparison of Efficiencies by Acid-Treated and Nonacid-Treated B.O.D.

	B. O. D. - p.p.m.				Efficiencies - Per Cent			
	Raw Sewage	Primary Effluent	Final Effluent		Primary	Secondary		Difference, Units 1 and 2
			Unit 1	Unit 2		Unit 1	Unit 2	
24-Hour Composite Samples								
Period 1								
N.A.T.	174	135	67	69	22.4	50.4	48.9	- 1.5
A.T.	164	134	59	61	18.3	56.0	54.5	- 1.5
Ratio AT/NAT	0.94	0.99	0.88	0.88				
Difference					4.1	5.6	5.6	0.0
Period 2								
N.A.T.	128	85	35	39	33.6	58.8	54.1	- 4.7
A.T.	116	80	27	30	31.1	66.3	62.5	- 3.8
Ratio AT/NAT	0.91	0.94	0.77	0.77				
Difference					2.5	7.5	8.4	0.9
Period 3								
N.A.T.	141	101	34	32	28.4	66.3	68.3	2.0
A.T.	134	96	27	24	28.4	71.9	75.0	3.1
Ratio AT/NAT	0.95	0.95	0.79	0.75				
Difference					0.0	5.6	6.7	1.1
4-Hour Composite Samples								
Period 1								
N.A.T.	298	201	91	93	32.5	54.7	53.8	- 0.9
A.T.	284	198	85	87	30.2	57.1	56.0	- 1.1
Ratio AT/NAT	0.95	0.98	0.93	0.94				
Difference					2.3	2.4	2.2	0.2
Period 2								
N.A.T.	195	118	43	50	39.5	63.6	57.6	- 6.0
A.T.	191	116	37	40	39.3	68.1	65.5	- 2.6
Ratio AT/NAT	0.98	0.98	0.86	0.80				
Difference					0.2	4.5	7.9	3.4
Period 3								
N.A.T.	240	147	46	41	38.8	68.7	72.1	3.4
A.T.	238	145	38	32	39.1	73.8	78.0	4.2
Ratio AT/NAT	0.99	0.99	0.83	0.78				
Difference					0.3	5.1	5.9	0.8

During periods 2 and 3, B.O.D. determinations were made on the settled filter effluents in addition to the final clarifier effluents, to determine whether increased detention time in the final clarifier of unit 2 was affecting the biochemical oxygen demand of the effluent.

Table 8. B.O.D. Averages - 24-hour Tests

	Filter Effluent		Settled Filter Effluent		Final Clarifier Effluent	
Unit	1	2	1	2	1	2
Period 2	65	73	26	30	35	39
Period 3	57	53	33	32	34	32

In period 3, the one-hour laboratory settling and clarifier results were the same. In period 2, the clarifier gave results that were about 32 per cent higher than the one-hour laboratory settling, but the effect was about the same in both clarifiers - 9 p.p.m. B.O.D. more in each case.

The raw sewage (N.A.T.) B.O.D. averaged 154 p.p.m. for the 24-hour composites and 250 p.p.m. for the 4-hour composites for the four test periods. The maximum B.O.D. was 238 for the 24-hour, and 527 for the 4-hour composites.

The B.O.D. ranged from 46 to 175 p.p.m. in the primary clarifier effluent; the average was 115 p.p.m. for 24-hour composite samples. Primary clarifier effluent consisted of settled raw sewage, and resettled secondary clarifier underflow recirculation.

The plant effluent averaged 68 p.p.m. (N.A.T.) B.O.D. without recirculation in period 1, with Unit 1 giving a slightly better effluent than Unit 2. In periods 3 and 4, Unit 1 with recirculation of plant effluent, gave an average (N.A.T.) B.O.D. effluent of 46 p.p.m.; and Unit 2, with direct recirculation of filter effluent, gave a plant effluent of 39 p.p.m. The 4-hour composites gave about the same picture - in period 1 (without recirculation), the effluents averaged 92 p.p.m., and in periods 3 and 4, with recirculation, Unit 1 effluent averaged 56 p.p.m., and Unit 2 effluent, 48 p.p.m. During the normal parallel operation, Unit 2 had, on the average, a better filter effluent than Unit 1, but the final effluent was not as good.

Suspended Solids Determinations

Summaries of the results of suspended solids determinations by operational periods will be found in Tables 9 and 10.

The average suspended solids in the raw sewage, based on the 24-hour composites, during the four periods, were: total, 134 p.p.m.; fixed, 36 p.p.m.; and volatile, 98 p.p.m. The results on the 4-hour composites show an average raw sewage suspended solids of: total, 204 p.p.m.; fixed, 48 p.p.m.; and volatile, 156 p.p.m. The maximum values of total, fixed, and volatile suspended solids in the 24-hour composite samples of raw sewage were 216, 112, and 192 p.p.m., respectively.

The total suspended solids ranged from 43 to 116 p.p.m. in the primary clarifier effluent, averaging 77 p.p.m. The primary clarifier effluent consisted of settled raw sewage, and resettled secondary clarifier underflow recirculation.

The results of the 24-hour tests show that the suspended solids of the effluent are about the same in all periods, although in period 1 the percentage of nonvolatile matter was somewhat less. During the warm weather test period, both methods of recirculation produced comparable effluents, but during the cold weather test period, the direct recirculation method gave higher volatile suspended solids in the filter effluent and lower volatile suspended solids in the plant effluent. The 4-hour composite samples gave similar results.

Nitrogen Determination

A summary of the nitrogen results for each period will be found in Table 11.

There was very little nitrification at any time, but Unit 2 always had higher nitrite and nitrate nitrogen in filter effluent and plant effluent. During the warm weather test period, both units produced more nitrite than nitrate nitrogen, but in the cold weather test period, the situation was reversed. This change was more pronounced in the unit with direct recirculation.

Grab Samples

The range of the pH and dissolved oxygen determinations for each period will be found in Table 12. Settleable solids were run during the first three periods. The range of results is shown in Table 13.

Table 9 - Summarized Suspended Solids Results (p.p.m.), 24-Hour Composite Samples

	Total								Fixed								Volatile							
	Raw Sewage	Primary Clarifier Effluent	Filter Influent		Filter Effluent		Final Effluent		Raw Sewage	Primary Clarifier Effluent	Filter Influent		Filter Effluent		Final Effluent		Raw Sewage	Primary Clarifier Effluent	Filter Influent		Filter Effluent		Final Effluent	
			1	2	1	2	1	2			1	2	1	2	1	2			1	2	1	2	1	2
	May 18 - June 6 (6)* Period 1 - Normal Parallel Operation																							
Avg	115	87			76	75	36	37	25	16			13	15	2	4	90	72			63	60	34	33
Max	132	97			98	134	49	50	38	24			20	35	4	9	103	79			82	99	45	41
Min	76	80			45	52	26	24	13	5			1	5	0	1	63	63			39	46	25	23
	June 9 - July 7 (9) Period 2 - Adjustment of Secondary Units to Recirculation																							
Avg	116	64			50	99	21	30	34	15			13	34	3	8	82	49			37	65	18	22
Max	178	91			107	372	38	62	95	33			26	165	7	28	135	76			81	207	31	34
Min	57	43			22	23	12	18	13	3			5	4	0	1	44	33			14	18	10	15
	July 10 - 26 (9) Period 3 - Warm Weather Test Period																							
Avg	128	75			50	48	23	22	32	15			13	12	5	4	96	60			37	37	19	17
Max	201	104			72	79	35	29	57	23			22	24	11	10	150	82			50	68	25	26
Min	101	59			38	23	14	13	17	7			5	1	0	0	61	36			22	16	11	6
	Nov. 28 - Dec. 7 (7) Period 4 - Cold Weather Test Period																							
Avg	178	88	76	92	56	74	53	41	53	15	19	24	11	14	11	10	125	73	57	74	45	62	42	31
Max	216	116	84	134	72	110	69	64	112	26	26	38	22	38	20	18	192	96	70	108	54	92	57	56
Min	116	44	62	24	32	50	34	22	20	0	12	0	4	0	0	2	66	20	50	14	28	48	30	16
	July 10 - Dec. 7 (16) Periods 3 and 4 - Both Warm and Cold Weather Test Periods																							
Avg	150	80			53	60	36	30	41	15			12	13	7	7	109	66			41	51	29	23
Max	216	116			72	110	69	64	112	26			22	38	20	18	192	96			54	92	57	56
Min	101	44			32	23	14	13	17	0			4	0	0	0	61	20			22	16	11	6

* Figure in parentheses indicates number of tests in group.

Table 10 - Summarized Suspended Solids Results (p.p.m.), 4-Hour Composite Samples

	Total								Fixed								Volatile							
	Raw Sewage	Primary Clarifier Effluent	Filter Influent		Filter Effluent		Final Effluent		Raw Sewage	Primary Clarifier Effluent	Filter Influent		Filter Effluent		Final Effluent		Raw Sewage	Primary Clarifier Effluent	Filter Influent		Filter Effluent		Final Effluent	
			1	2	1	2	1	2			1	2	1	2	1	2			1	2	1	2	1	2
May 22 - June 6 (7)* Period 1 - Normal Parallel Operation																								
Avg	205	124			136	120	50	55	48	25			29	23	5	8	158	99			107	97	45	47
Max	265	137			191	176	66	72	92	34			60	43	10	16	184	111			131	133	56	56
Min	150	106			72	72	37	45	28	16			8	10	1	0	122	90			64	61	34	38
June 9 - July 7 (9) Period 2 - Adjustment of Secondary Units to Recirculation																								
Avg	176	86			71	102	29	42	44	18			18	30	5	10	132	68			53	71	24	32
Max	240	120			183	280	61	72	60	28			49	112	11	27	192	99			134	168	50	56
Min	113	52			21	30	16	18	24	7			1	8	0	2	83	45			20	22	12	16
July 10-26 (9) Period 3 - Warm W eather Test Period																								
Avg	202	98			56	53	33	30	52	20			13	13	7	8	150	79			43	40	26	22
Max	410	150			114	101	61	59	100	36			36	27	13	15	310	114			54	80	48	49
Min	51	52			22	25	19	17	20	6			2	1	0	1	31	35			13	17	13	10
Nov. 28 - Dec. 7 (7) Period 4 - Cold Weather Test Period																								
Avg	239	130	113	123	108	125	70	69	49	26	36	25	24	28	12	16	191	104	78	98	84	97	59	53
Max	434	182	178	152	162	150	112	114	94	36	90	32	34	36	22	24	340	148	120	132	128	118	92	90
Min	166	104	82	82	78	94	96	50	30	12	12	14	14	18	0	9	136	82	42	68	58	68	36	34
July 10 - Dec. 7 (16) Periods 3 and 4, Both Warm and Cold Weather Test Periods																								
Avg	218	112			75	84	50	47	51	22			18	20	9	11	168	90			61	65	40	36
Max	434	182			162	150	112	114	100	36			36	36	22	24	340	148			128	118	92	90
Min	51	52			22	25	19	17	20	6			2	1	0	1	31	35			13	17	13	10

* Figure in parentheses indicates number of tests in group.

Table 11 - Summarized Nitrogen Results, 24-Hour Composite Samples

	Organic								Ammonia							
	Raw Sewage	Primary Clarifier Effluent	Filter Influent 1	Filter Influent 2	Filter Effluent 1	Filter Effluent 2	Final Effluent 1	Final Effluent 2	Raw Sewage	Primary Clarifier Effluent	Filter Influent 1	Filter Influent 2	Filter Effluent 1	Filter Effluent 2	Final Effluent 1	Final Effluent 2
	May 18 - June 6 (6)* Period 1 - Normal Parallel Operation															
Avg	10.7	9.0	9.7	9.6	9.5	8.7			11.6	12.0	11.6	11.3	10.2	10.4		
Max	16.0	14.0	14.0	14.5	13.0	11.6			12.5	12.5	12.0	12.0	11.0	11.5		
Min	6.7	4.3	5.3	4.7	3.5	3.0			10.0	11.5	11.0	10.0	10.0	10.0		
	June 9 - July 7 (9) Period 2 - Adjustment of Secondary Units to Recirculation															
Avg	8.0	7.1	6.1	8.2	6.5	8.1			8.1	7.2	6.4	6.0	5.5	5.7		
Max	13.2	10.7	10.8	13.2	13.2	15.5			11.0	11.0	10.0	10.0	10.0	10.0		
Min	3.4	3.8	2.2	4.7	0.8	3.9			5.0	3.0	3.0	2.0	2.0	2.0		
	July 10-26 (9) Period 3 - Warm Weather Test Period															
Avg	7.3	6.1	4.9	6.0	4.3	4.0			11.2	10.6	9.7	9.0	8.8	7.7		
Max	10.7	8.6	6.6	11.2	5.5	8.1			14.0	14.0	13.0	12.5	12.0	11.0		
Min	3.8	3.8	3.1	3.6	2.3	1.9			7.5	7.5	7.0	7.0	6.5	5.5		
	Nov. 28 - Dec. 7 (7) Period 4 - Cold Weather Test Period															
Avg	14.7	13.1	10.8	11.0			8.5	6.9	16.4	16.8	15.4	14.9			14.9	14.4
Max	18.7	15.6	16.3	14.5			16.4	15.2	18.0	18.0	16.5	16.5			16.5	16.5
Min	9.2	8.2	5.4	7.1			2.9	0.3	15.0	15.0	14.0	13.0			13.0	12.0
	July 10 - Dec. 7 (16) Periods 3 and 4 - Both Warm and Cold Weather Test Periods															
Avg	10.5	9.2	7.5	8.2					13.5	13.3	12.2	11.6				
Max	18.7	15.6	16.3	14.5					18.0	18.0	16.5	16.5				
Min	3.8	3.8	3.1	3.6					7.5	7.5	7.0	7.0				

	Nitrite N								Nitrate N							
	Raw Sewage	Primary Clarifier Effluent	Filter Influent 1	Filter Influent 2	Filter Effluent 1	Filter Effluent 2	Final Effluent 1	Final Effluent 2	Raw Sewage	Primary Clarifier Effluent	Filter Influent 1	Filter Influent 2	Filter Effluent 1	Filter Effluent 2	Final Effluent 1	Final Effluent 2
	May 18 - June 6 (6) Period 1 - Normal Parallel Operation															
Avg		0.75	0.56	0.54	0.48	0.50	0.48	0.51		0.18	0.17	0.14	0.33	0.38	0.15	0.24
Max		2.00	1.00	1.00	0.70	0.65	0.70	0.80		0.40	0.40	0.20	0.40	0.60	0.20	0.40
Min		0.40	0.30	0.30	0.17	0.27	0.25	0.17		0.10	0.10	0.10	0.16	0.16	0.10	0.14
	June 9 - July 7 (9) Period 2 - Adjustment of Secondary Units to Recirculation															
Avg		1.01	1.01	1.38	1.13	1.85	1.22	1.85		0.90	0.67	1.07	0.83	1.30	0.80	1.34
Max		2.20	2.50	2.80	2.60	3.50	3.00	3.50		4.00	1.60	4.00	2.00	3.00	1.60	4.00
Min		0.15	0.20	0.25	0.20	0.30	0.20	0.30		0.04	0.08	0.08	0.12	0.12	0.14	0.12
	July 10-26 (9) Period 3 - Warm Weather Test Period															
Avg		0.46	0.71	1.33	0.78	1.96	0.92	2.09		0.09	0.15	0.28	0.27	0.57	0.24	0.66
Max		0.85	1.00	1.80	1.00	2.50	1.20	2.90		0.30	0.30	0.40	0.40	1.00	0.36	1.20
Min		0.00	0.50	1.00	0.40	1.50	0.70	1.70		0.02	0.10	0.18	0.20	0.30	0.18	0.36
	Nov. 28 - Dec. 7 (7) Period 4 - Cold Weather Test Period															
Avg	0.06	0.07	0.12	0.18			0.16	0.20							0.35	1.39
Max	0.10	0.12	0.16	0.25			0.24	0.26							0.80	2.80
Min	0.04	0.01	0.06	0.13			0.12	0.16							0.12	0.24
	July 10 - Dec. 7 (16) Periods 3 and 4 - Both Warm and Cold Weather Test Periods															
Avg		0.31	0.47	0.87			0.62	1.26							0.28	0.98
Max		0.85	1.00	1.80			1.20	2.90							0.80	2.80
Min		0.00	0.06	0.13			0.12	0.16							0.12	0.24

* Figure in parentheses indicates number of tests in group.

Table 12 - Range of Grab Sample Determinations

	Raw Sewage	Primary Clarif. Effl.	Filter Influent		Filter Effluent		Final Effluent	
			1	2	1	2	1	2
pH DETERMINATIONS - RANGE								
May 22 - June 6 (8)* Period 1 - Normal Parallel Operation								
Range	7.4-9.4	7.2-8.9	7.3-8.8	7.3-8.8	7.7-8.4	7.7-8.4		
June 9-July 7(10) Period 2-Adjustment of Secondary Units to Recirculation								
Range	7.3-9.0	7.3-8.0	7.4-7.9	7.5-7.9	7.5-8.1	7.5-8.5		
July 10-26 (9) Period 3 - Warm Weather Test Period								
Range	7.3-8.4	7.2-7.7	7.3-7.8	7.5-7.8	7.5-8.0	7.7-8.1		
Nov. 28 - Dec. 7 (7) Period 4 - Cold Weather Test Period								
Range	7.3-9.6/	7.3-8.7	7.3-8.5	7.5-8.7	7.5-8.4	7.6-8.4	7.4-8.0	7.3-8.2
July 10-Dec.7(16) Periods 3 and 4-Both Warm and Cold Weather Test Periods								
Range	7.3-9.6/	7.2-8.7	7.3-8.5	7.5-8.7	7.5-8.4	7.6-8.4		
D. O. DETERMINATIONS (p. p. m.)								
May 22 - June 6 (8) Period 1 - Normal Parallel Operation								
Range	0.0-5.7	0.0-1.5	1.7-8.8	0.9-4.6	2.9-7.2	3.3-7.3		
June 9-July 7(10) Period 2-Adjustment of Secondary Units to Recirculation								
Range	0.0-5.7	0.0-4.3	0.8-7.0	2.4-9.0	1.2-8.3	1.6-9.5		
July 10-26 (9) Period 3 - Warm Weather Test Period								
Range	0.0-4.5	0.0-1.5	1.0-5.2	2.9-6.7	3.1-6.7	4.7-7.6		
Nov. 28 - Dec. 7 (7) Period 4 - Cold Weather Test Period								
Range	0.0-4.0	0.0-2.6	2.8-6.6	3.5-8.0	4.4-7.8	5.0-8.2	2.4-6.7	3.1-6.8
July 10-Dec.7 (16) Periods 3 and 4-Both Warm and Cold Weather Test Periods								
Range	0.0-4.5	0.0-2.6	1.0-6.6	2.9-8.0	3.1-7.8	4.7-8.2		

* Number of test days in period.

Table 13. Settleable Solids - ml/L

	Raw Sewage	Primary Clarified Effluent	Filter Influent		Filter Effluent	
			1	2	1	2
Period 1	Tr. - 6.0	0.0 - 0.5	Tr. - 0.2	Tr. - 0.6	Tr. - 4.0	0.1 - 4.5
Period 2	Tr. - 11.0	0.0 - 0.5	0.0 - 0.8	Tr. - 3.5	Tr. - 17.0	Tr. - 23.0
Period 3	0.1 - 8.5	0.0 - 0.1	Tr. - 0.45	Tr. - 0.6	Tr. - 2.5	Tr. - 1.0

9. Biological Data

The complete biological report of the trickling filter study at Webster City will be found in Appendix A. Biological examinations were made during the four periods of the study, and the results are a necessary supplement to the engineering report because they show the change in the balance of the various forms of organisms that may have caused the differences in efficiencies.

During the normal parallel operation, both filters contained a large amount of a humus-like black material along with sulphur salts and putrescible matter. Both filters showed some ponding. After recirculation was started, the filter with direct circulation no longer showed signs of ponding and the growth changed to a brownish-gray slime. Some ponding was apparent on the other filter (recirculating final effluent) during the entire study period.

When the loading on the filters was increased by recirculation, the concentration of scouring organisms increased on both filters, but the concentration was nearly five times as much in Filter 2. The population of bacteria also increased in both filters, but was in higher concentration in Filter 1. Many organisms seem to be returned to the filter when direct recirculation is used; this is most evident in the case of the free-living organisms, but it is also true for the scouring and attached types.

10. Loadings and Efficiencies

The study conducted at Webster City has been divided into four periods. In the first period, the two secondary units were in normal parallel operation, so that it could be shown that the treatment efficiencies of the filters were similar, and that any difference in later periods would presumably be attributable to differences in operation procedures. This first period was from May 18 to June 6, and analytical data were obtained on six 24-hour composite, and seven 4-hour composite samples. The second period, or period of adjustment, extended from June 9 until July 7. This was a much longer time than would be anticipated as necessary for the filters to adjust to recirculation, but there were many days that the plant was not operated due to high storm water flows. During this period, nine 24-hour and nine 4-hour test runs were made. The third period was for the comparison of the results of the two methods of recirculation during warm weather. Between July 10 and July 26, nine runs were made on both the 24-hour and the 4-hour basis. In the fourth period, from November 28 to December 7, seven runs were made, using 24-hour and 4-hour composite samples, for comparison of the methods of recirculation during cold weather.

A summary of the results of the loadings and efficiencies for each period will be found in Table 14. This table also shows the results for periods 3 and 4 combined, to indicate typical efficiencies that might be expected over extended periods of operation.

The loadings, removals and efficiencies were calculated from formulae that were developed from the flow diagram. A list of the formulae used will be found in Appendix B.

The efficiency, based on B.O.D. removal, of the primary tank, was never very great. It averaged 17.3%, 23.8%, 23.1%, & 10.3% on the 24-hour composite samples in the four periods. The 4-hour test results were higher - 26.5%, 31.1%, 33.2%, and 27.7% for the four periods. During the entire study, the efficiency of the primary unit for B.O.D. removal, computed from the 24-hour composites, averaged 19.2%; but the efficiency averaged 14.3% for runs when the raw sewage B.O.D. was over the median value of 150 p.p.m., and 23.7% when the raw sewage B.O.D. was less than 150 p.p.m. Comparison of B.O.D. efficiencies on the basis of raw sewage flow rates gives equally unexpected results. When the flow was more than the median of 0.583 m.g.d., the efficiency was 21.8% and, when the flow was less than the median, the efficiency was 16.9%.

The primary settling tank efficiency, based on the removal of suspended solids during the 24-hour tests, was more in accordance with what would normally be expected with domestic sewage from combined sewers. The primary tank removed 16.9%, 34.4%, 35.8%, and 45.8% of

the suspended solids in the raw sewage during the four periods. During the entire study, the efficiency of the primary unit for suspended solids removal averaged 34.5%, and the efficiency averaged 40.4% for runs when the raw sewage suspended solids were over 119 p.p.m., and 28.5% when they were less than 119 p.p.m. Within the range of flow rates studied, the flow rate was not a limiting factor in suspended solids removal by the primary tank. During runs at both high and low rate flows, the average removal was practically the same.

The load of settled raw sewage from the primary clarifier to each secondary unit (based on filter dimensions) averaged 8.8 m.g.a.d., and 0.88 lbs. B.O.D./cu.yd/day during the period of parallel operation with no secondary recirculation, and 9.8 m.g.a.d. and 0.90 lbs. B.O.D./cu.yd/day during the combined warm and cold weather periods for comparing the two methods of secondary recirculation. The actual loads to the filters, including all recirculation, averaged 10.0 m.g.a.d. and 0.93 lbs. B.O.D./cu.yd/day with no secondary recirculation and 21.0 m.g.a.d. and 1.24 lbs. B.O.D./cu.yd/day during the last two periods.

From analysis of the 24-hour test runs, it can be seen that the secondary units removed an average of 0.46 lbs. B.O.D. per cubic yard of filter medium per day during the first period, with Unit 1 having a slightly greater removal than Unit 2. During the third and fourth periods, the secondary B.O.D. removal averaged 0.62 pounds per cubic yard of filter medium per day. During these periods, Unit 2 averaged 0.04 pounds B.O.D./cu.yd/day removal more than Unit 1.

The range of secondary unit efficiencies was 43.9% to 67.9% during period 1, and 46.9% to 85.8% during periods 3 and 4. Although the efficiencies of the two secondary units varied over a wide range, in thirteen of sixteen 24-hour test runs, the efficiency of Unit 2, with direct recirculation, was equal to or greater than the efficiency of the unit with recirculation of final effluent. The average efficiencies of Unit 1 (effluent recirculation) and Unit 2 (direct recirculation) in periods 3 and 4 combined were 65.5% and 71.0%, respectively.

The relationships between the pounds of settled raw sewage B.O.D. applied to the secondary units and the pounds of B.O.D. removed per cu.yd. of filter medium per day under various conditions of operation, are shown in Figures 14 to 23. The line of best fit was determined in each case from the recorded data by the method of least squares. The equations of the curves and their respective coefficients of correlation are summarized in Table 15.

Figures 14 and 15 show, for the 24-hour runs in periods 3 and 4 combined, the relationship between B.O.D. applied and removed. The points for each day are plotted to show the variations that occurred.

Figure 16 shows the difference between Unit 1 and Unit 2 for normal parallel operation; Unit 1 has increasingly better results than Unit 2 as the applied load is increased. Figure 17 shows the consistently better results of Unit 2 for all loadings within the range of the tests, during periods 3 and 4. Figures 18 and 19 show the variations for the secondary units in the three comparison test periods. The lengths of the curves cover the approximate ranges of the test data. Figures 20 to 23 show the results for the 4-hour test runs.

Most of the curves have data with a considerable or high correlation, the exceptions being the 4-hour tests in period 1, and the 24-hour tests in period 4. For periods 3 and 4 combined, the curves show high correlation between B.O.D. loadings and removals.

	Residual BOD in Settled Raw Sewage Per Cent	Settled Raw Sewage Loadings Applied to Each Secondary Unit			Secondary Process - Filter and Final Clarifier												Over-all Plant Efficiency Primary Plus	
					Unit 1 - Recirculation of Final Effluent						Unit 2 - Direct Recirculation							
		BOD			Filter Loading			BOD Removal		Effi-	Filter Loading			BOD Removal		Effi-		
		Flow MGAD	lbs/day	lbs/cu.yd /day	Flow MGAD	lbs/day	lbs/cu.yd /day	lbs/day	lbs/cu.yd /day	ciency	Flow MGAD	lbs/day	lbs/cu.yd /day	lbs/day	lbs/cu.yd /day	ciency	Unit 1	Unit 2
TWENTY-FOUR HOUR COMPOSITE SAMPLES																		
					May 18 - June 6 Six Days Period 1 - Normal Parallel Operation													
Avg	82.7	8.8	304	0.877	10.0	324	0.936	162	0.468	54.2	10.0	318	0.924	157	0.452	52.5	61.8	60.5
Max	90.9	10.2	402	1.162	11.6	425	1.231	227	0.656	66.6	11.6	430	1.245	222	0.641	67.9	74.3	75.5
Min	75.7	7.1	215	0.622	8.0	232	0.672	137	0.395	46.1	8.0	242	0.700	128	0.368	43.9	55.0	53.3
					June 9 - July 7 Nine Days Period 2 - Adjustment of Secondary Units to Recirculation													
Avg	76.2	12.1	274	0.792	24.0	363	1.051	178	0.515	65.1	24.9	453	1.270	164	0.477	56.0	73.5	69.1
Max	89.2	13.7	521	1.509	25.4	695	2.013	336	0.971	73.5	28.4	765	2.217	362	1.047	69.6	79.4	77.4
Min	55.3	10.4	186	0.502	22.5	219	0.635	103	0.299	54.0	22.5	191	0.552	39	0.113	18.7	65.0	55.0
					July 10-26 Nine Days Period 3 - Warm Weather Test Period													
Avg	76.9	10.3	270	0.780	21.4	361	1.040	184	0.539	66.8	21.5	415	1.200	190	0.549	70.8	75.4	77.6
Max	87.7	11.4	410	1.185	22.5	497	1.440	289	0.835	74.3	22.5	615	1.780	279	0.807	77.8	81.5	84.0
Min	70.1	9.0	108	0.312	19.9	195	0.564	60	0.174	60.0	20.3	189	0.545	75	0.217	61.0	69.0	69.6
					Nov. 28 - Dec. 7 Seven Days Period 4 - Cold Weather Test Period													
Avg	89.7	9.2	367	1.060	20.5	488	1.410	234	0.677	63.3	20.9	555	1.610	262	0.755	71.3	67.0	74.0
Max	108.8	10.5	475	1.324	21.8	532	1.539	328	0.947	85.8	23.4	667	1.928	328	0.947	85.5	88.1	87.5
Min	80.5	8.1	290	0.836	19.4	386	1.113	158	0.458	46.9	19.6	510	1.340	192	0.555	59.8	51.8	62.7
					July 10 - Dec. 7 Sixteen Days Periods 3 and 4 - Both Warm and Cold Weather Test Periods													
Avg	82.5	9.8	312	0.904	20.9	416	1.202	206	0.598	65.4	21.2	441	1.280	221	0.640	71.0	71.8	76.0
Max	108.8	11.4	475	1.324	22.5	532	1.539	328	0.947	85.8	23.4	667	1.928	328	0.947	85.5	88.1	87.5
Min	70.1	8.1	108	0.312	19.4	195	0.564	60	0.174	46.9	19.6	189	0.545	75	0.217	59.8	51.8	62.7
FOUR HOUR COMPOSITE SAMPLES																		
					May 22 - June 6 Seven Days Period 1 - Normal Parallel Operation													
Avg	73.5	11.5	561	1.625	12.6	600	1.735	316	0.916	56.7	12.6	603	1.740	310	0.897	55.5	67.9	67.0
Max	90.2	13.2	627	1.810	15.5	753	2.175	375	1.082	62.7	15.5	692	2.000	366	1.056	61.1	76.1	77.6
Min	57.7	7.4	458	1.325	8.0	475	1.375	284	0.820	48.5	8.0	475	1.375	265	0.767	47.5	53.6	55.1
					June 9 - July 7 Nine Days Period 2 - Adjustment of Secondary Units to Recirculation													
Avg	68.9	14.1	441	1.270	25.9	564	1.630	297	0.860	67.1	26.8	686	1.985	274	0.793	59.8	79.1	73.5
Max	81.0	15.0	740	2.140	27.8	1055	3.050	477	1.379	74.5	31.6	1258	3.638	505	1.460	69.7	85.4	82.8
Min	56.6	12.8	237	0.685	24.6	308	0.892	178	0.515	52.8	24.6	328	0.949	122	0.352	32.1	71.6	45.0
					July 10-26 Nine Days Period 3 - Warm Weather Test Period													
Avg	66.8	13.0	491	1.430	24.1	637	1.840	345	0.996	69.4	24.2	632	1.830	363	1.048	74.1	80.3	82.6
Max	80.1	14.5	770	2.225	25.6	946	2.740	548	1.585	80.4	25.8	1052	3.045	589	1.700	80.9	87.0	89.2
Min	55.4	11.8	155	0.449	22.8	238	0.687	82	0.236	52.9	23.0	285	0.823	108	0.314	63.4	73.1	78.2
					Nov. 28 - Dec. 7 Seven Days Period 4 - Cold Weather Test Period													
Avg	72.3	12.6	599	1.733	23.6	674	1.950	398	1.150	66.4	24.1	741	2.145	431	1.247	72.0	75.6	79.9
Max	81.3	14.7	784	2.265	25.8	997	2.880	523	1.512	74.0	26.4	1078	3.115	536	1.551	81.2	80.2	85.8
Min	67.1	10.9	494	1.430	21.9	318	0.921	323	0.934	59.8	22.2	577	1.665	330	0.954	66.9	69.0	77.2
					July 10 - Dec. 7 Sixteen Days Periods 3 and 4 - Both Warm and Cold Weather Test Periods													
Avg	69.2	12.8	539	1.557	23.9	654	1.885	368	1.064	68.1	24.1	680	1.970	392	1.134	73.2	78.4	81.4
Max	81.3	14.7	784	2.265	25.8	997	2.880	548	1.585	80.4	26.4	1078	3.115	589	1.700	81.2	87.0	89.2
Min	55.4	10.9	155	0.449	21.9	238	0.687	82	0.236	52.9	22.2	285	0.823	108	0.314	63.4	69.0	77.2

Table 15 - Loading versus Removal Curves

Curve	Equation *	Corrected Coefficient of Correlation
Period 1		
24-hour		
Unit 1	$y = 0.408x + 0.111$	0.624
Unit 2	$y = 0.384x + 0.116$	.574
4-hour		
Unit 1	$y = 0.310x + 0.413$	.234
Unit 2	$y = 0.339x + 0.347$	.174
Period 3		
24-hour		
Unit 1	$y = 0.747x - 0.044$	.980
Unit 2	$y = 0.760x - 0.044$	.913
4-hour		
Unit 1	$y = 0.695x + 0.010$	.941
Unit 2	$y = 0.695x + 0.062$	.928
Period 4		
24-hour		
Unit 1	$y = 0.931_x - 0.312$	.368
Unit 2	$y = 0.713x - 0.002$	.556
4-hour		
Unit 1	$y = 0.692x - 0.048$	.816
Unit 2	$y = 0.667x + 0.091$	.785
Periods 3 and 4		
24-hour		
Unit 1	$y = 0.689x - 0.023$	.742
Unit 2	$y = 0.684x + 0.022$	.880
4-hour		
Unit 1	$y = 0.673x + 0.016$	.922
Unit 2	$y = 0.684x + 0.070$	.985

* x = B.O.D. applied - pounds per cu.yd. of stone per day (settled raw sewage)

y = B.O.D. removed - pounds per cu.yd. of stone per day.

Figure 14

Relationship Between (N.A.T.) BOD Loading of Filters and Removal by Secondary Process
Unit 1 - Periods III and IV - 24 Hour Test

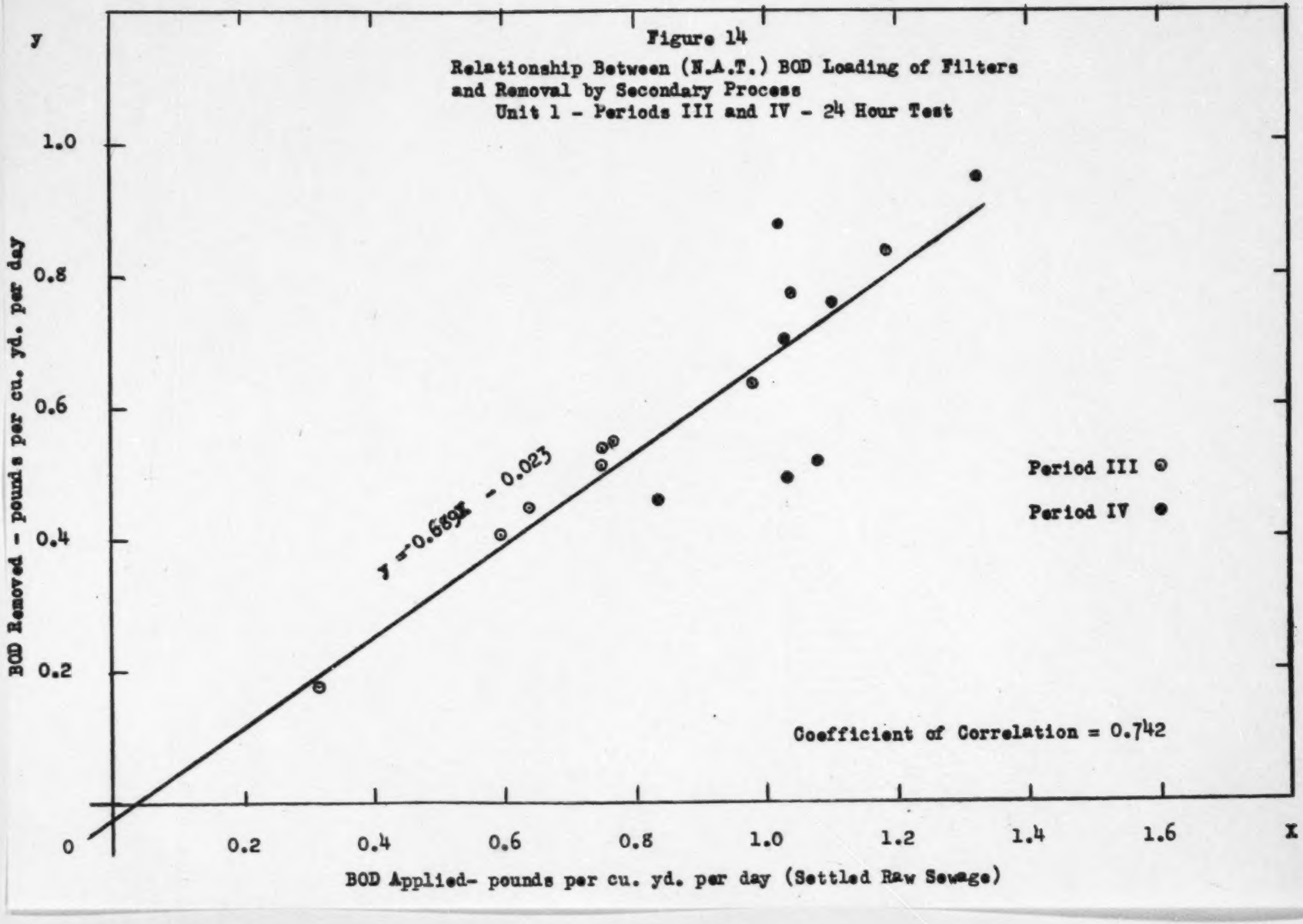


Figure 15
Relationship between (N.A.T.) BOD Loading of
Filter and Removal by Secondary Process
Unit 2 - Periods 3 and 4 - 24-Hour Test

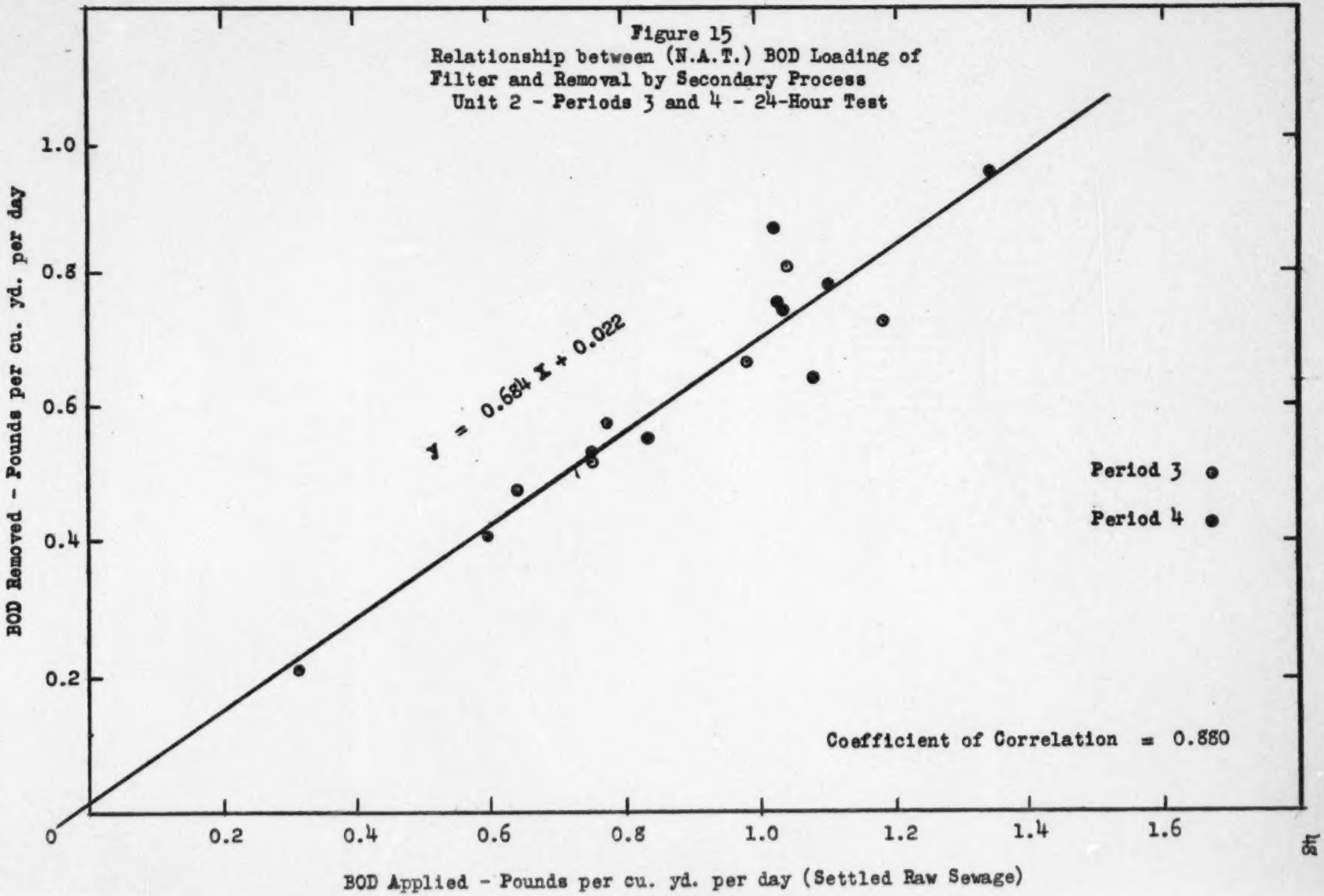


Figure 16
Relationship Between BOD (n.a.t.) Loading of Filters
and Removal by Secondary Process - 24 Hour Test
Period I

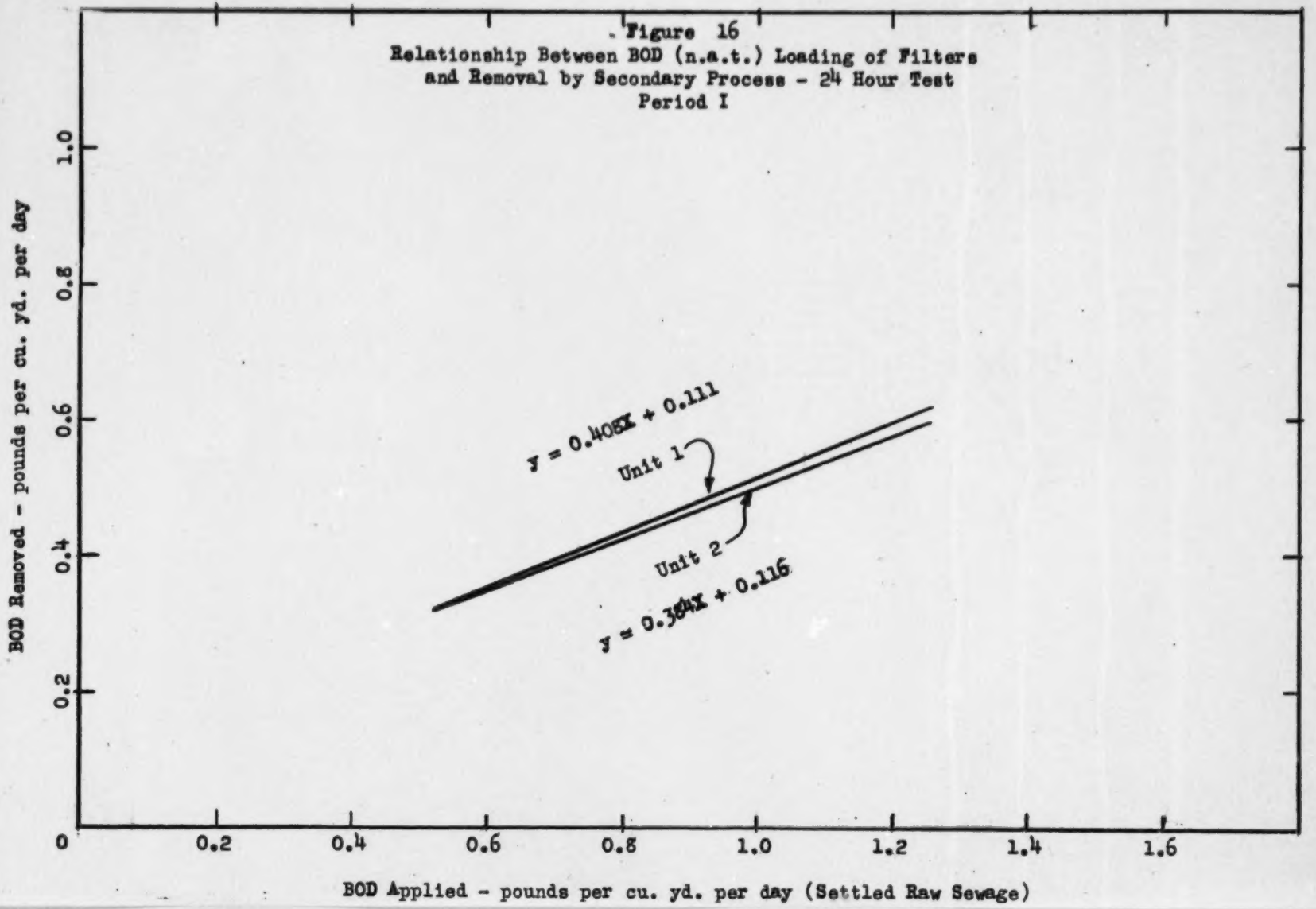


Figure 17
Relationship Between BOD (n.a.t.) Loading of Filters
and Removal by Secondary Process - 24 Hour Test
Periods III and IV

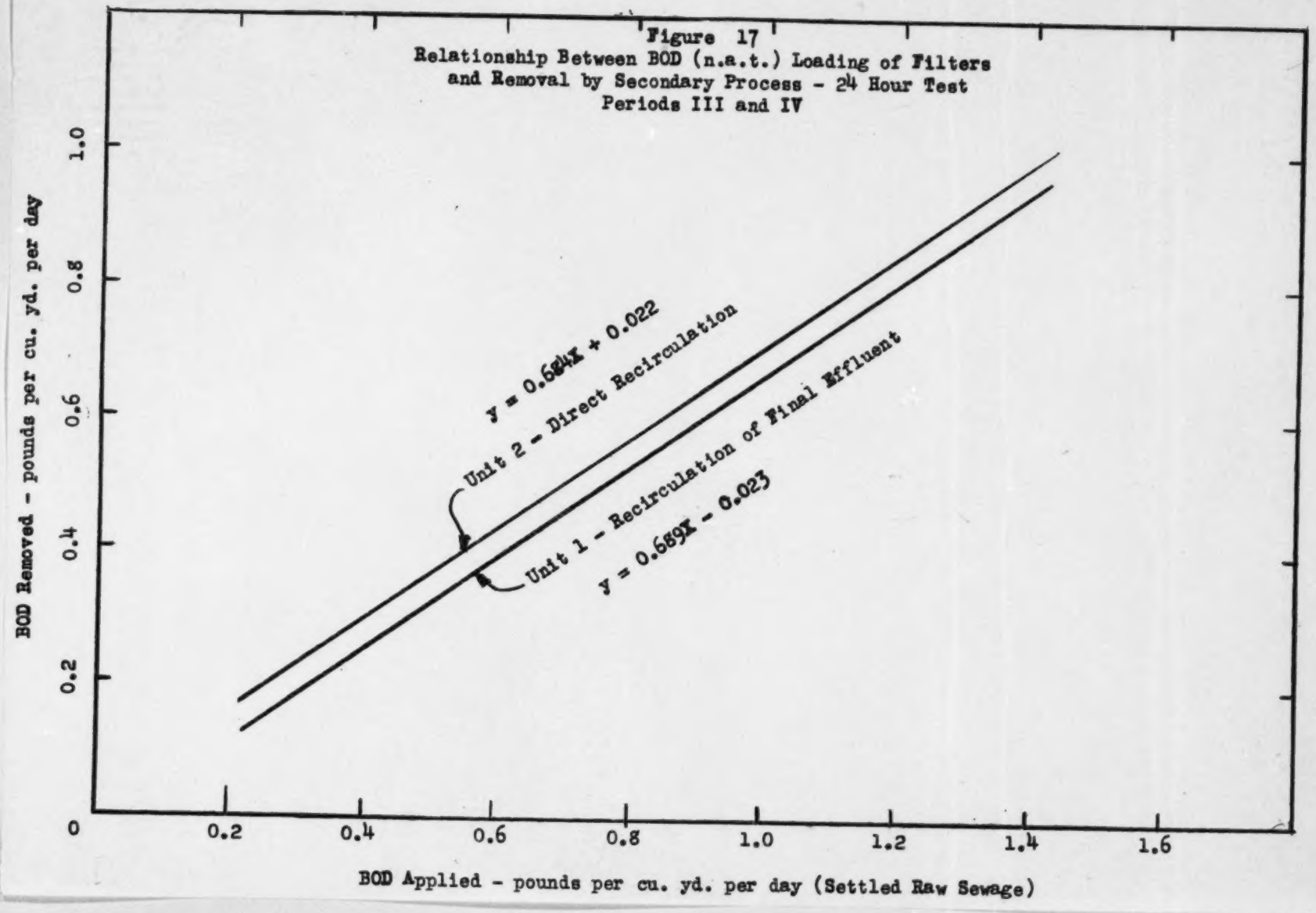


Figure 18
Relationship Between BOD (n.a.t.) Loading of Filters
and Removal by Secondary Process - 24 Hour Test
Unit 1

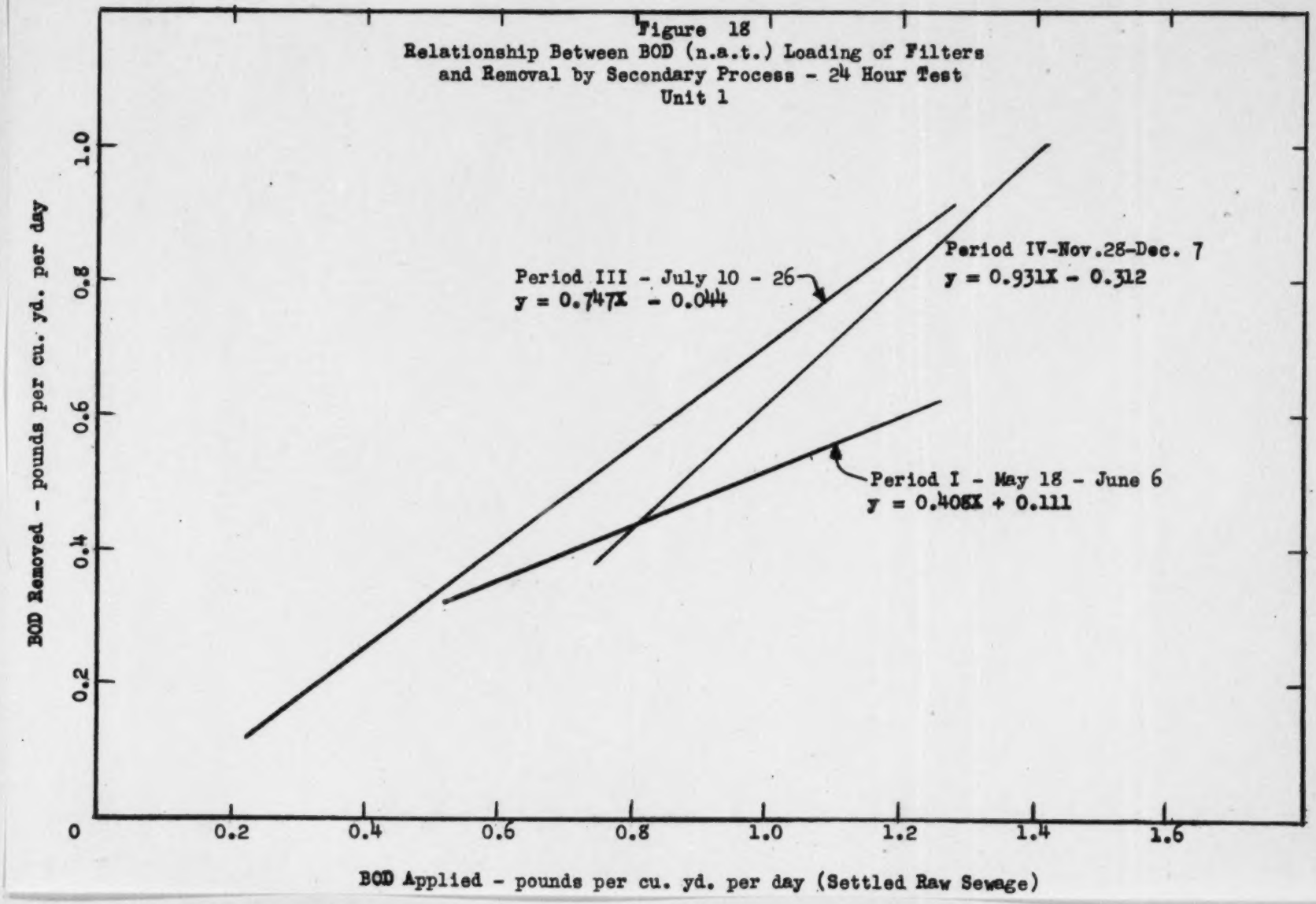


Figure 19
Relationship Between BOD (n.a.t.) Loading of Filters
and Removal by Secondary Process - 24 Hour Test
Unit 2

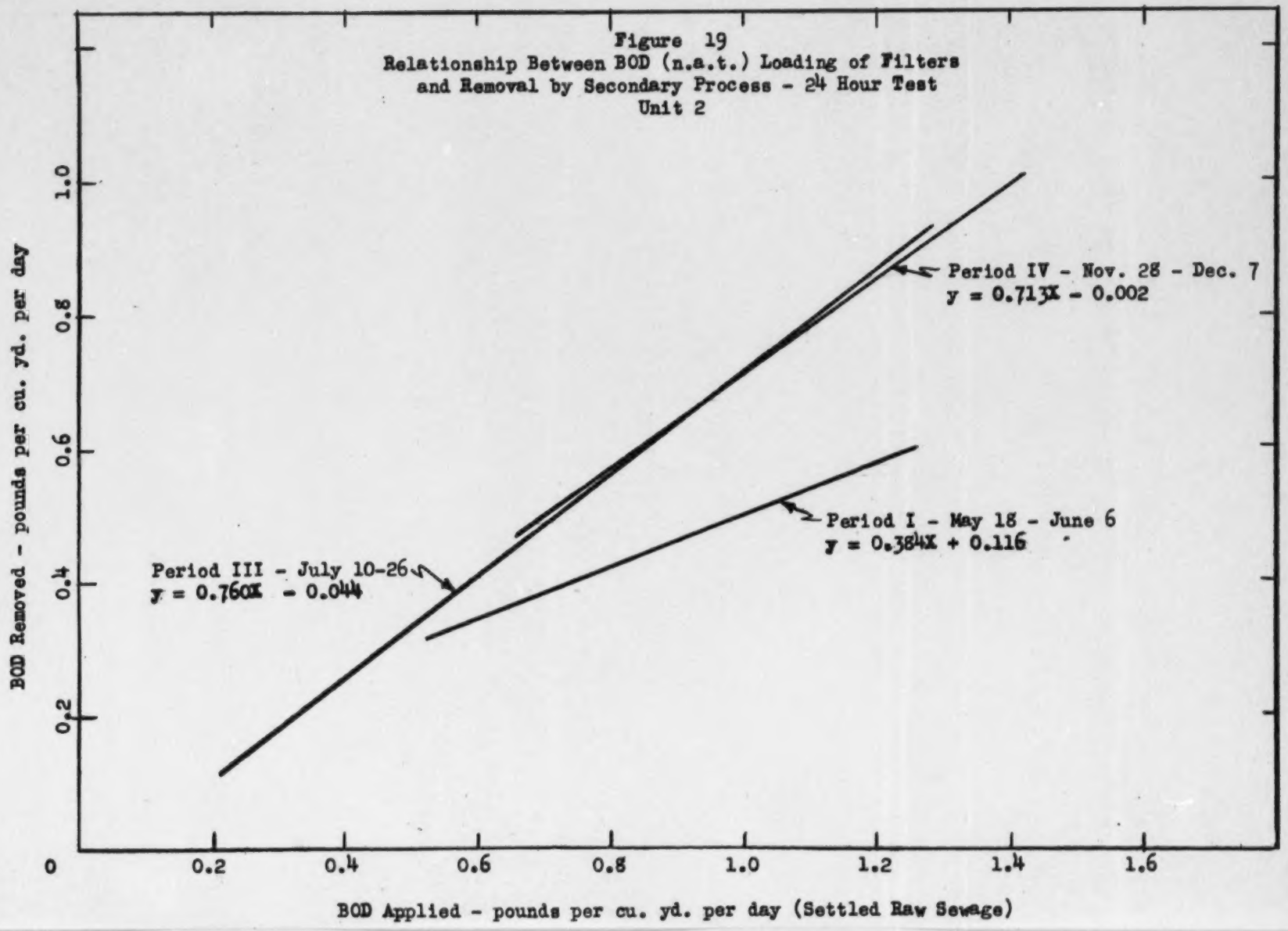


Figure 20
Relationship Between BOD (n.a.t.) Loading of Filters
and Removal by Secondary Process - 4 Hour Test
Period I

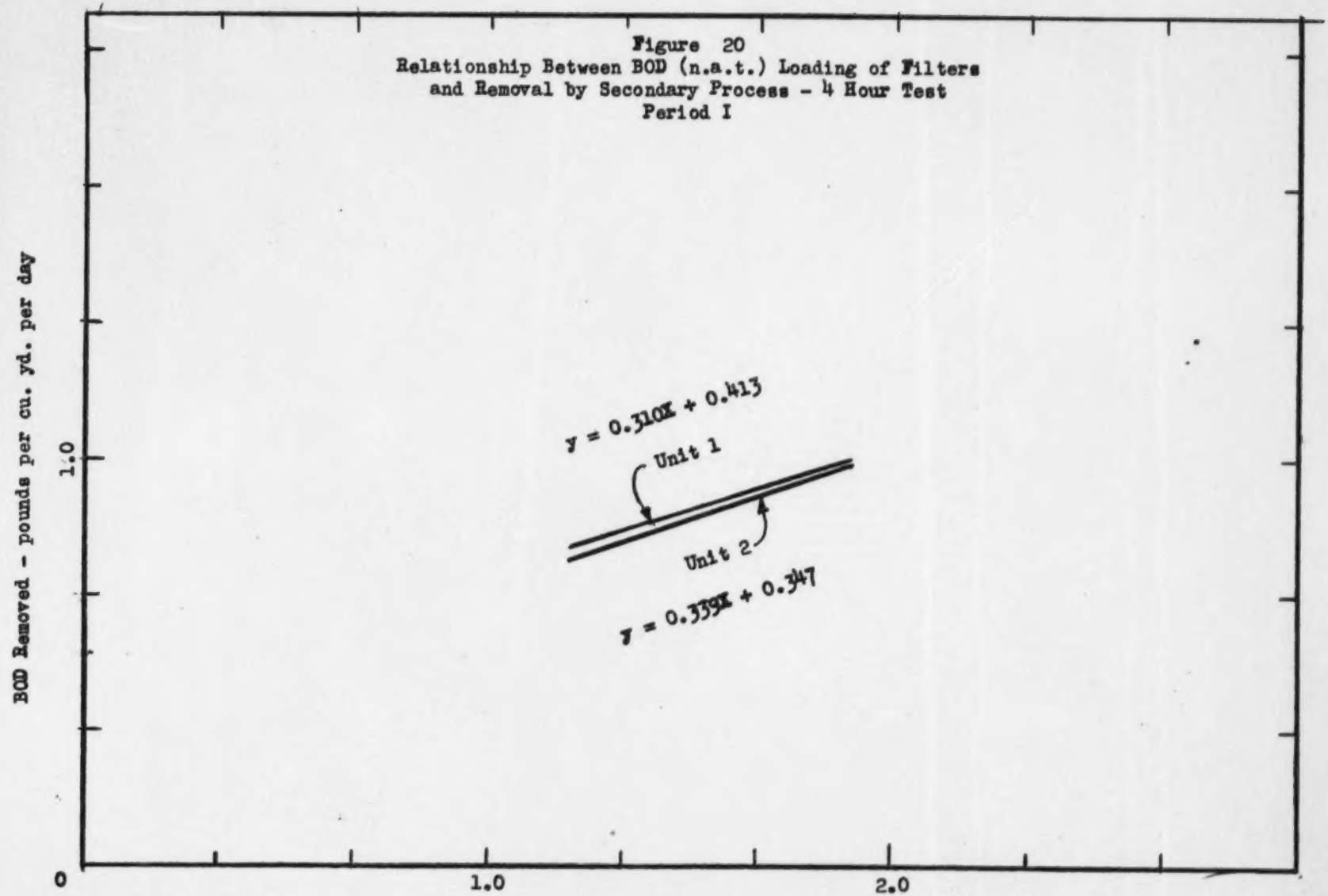


Figure 21
Relationship Between BOD (n.a.t.) Loading of Filters
and Removal by Secondary Process - 4 Hour Test
Periods III and IV

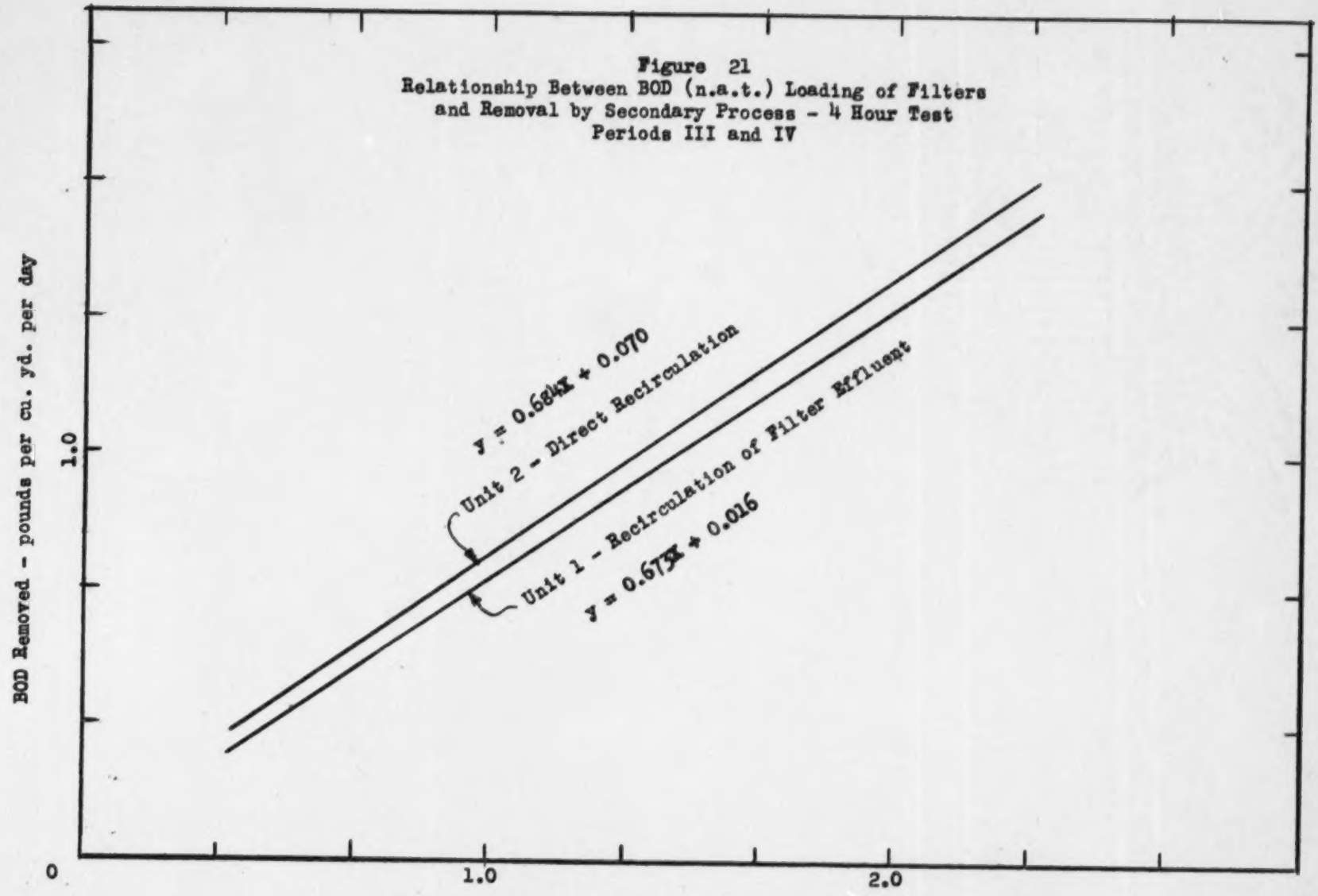

BOD Removed - pounds per cu. yd. per day
1.0
0
1.0
2.0
BOD Applied - pounds per cu. yd. per day (Settled Raw Sewage)
y = 0.68x + 0.070
Unit 2 - Direct Recirculation
Unit 1 - Recirculation of Filter Effluent
y = 0.67x + 0.016

Figure 22
Relationship Between BOD (n.a.t.) Loading of Filters
and Removal by Secondary Process - 4 Hour Test
Unit 1

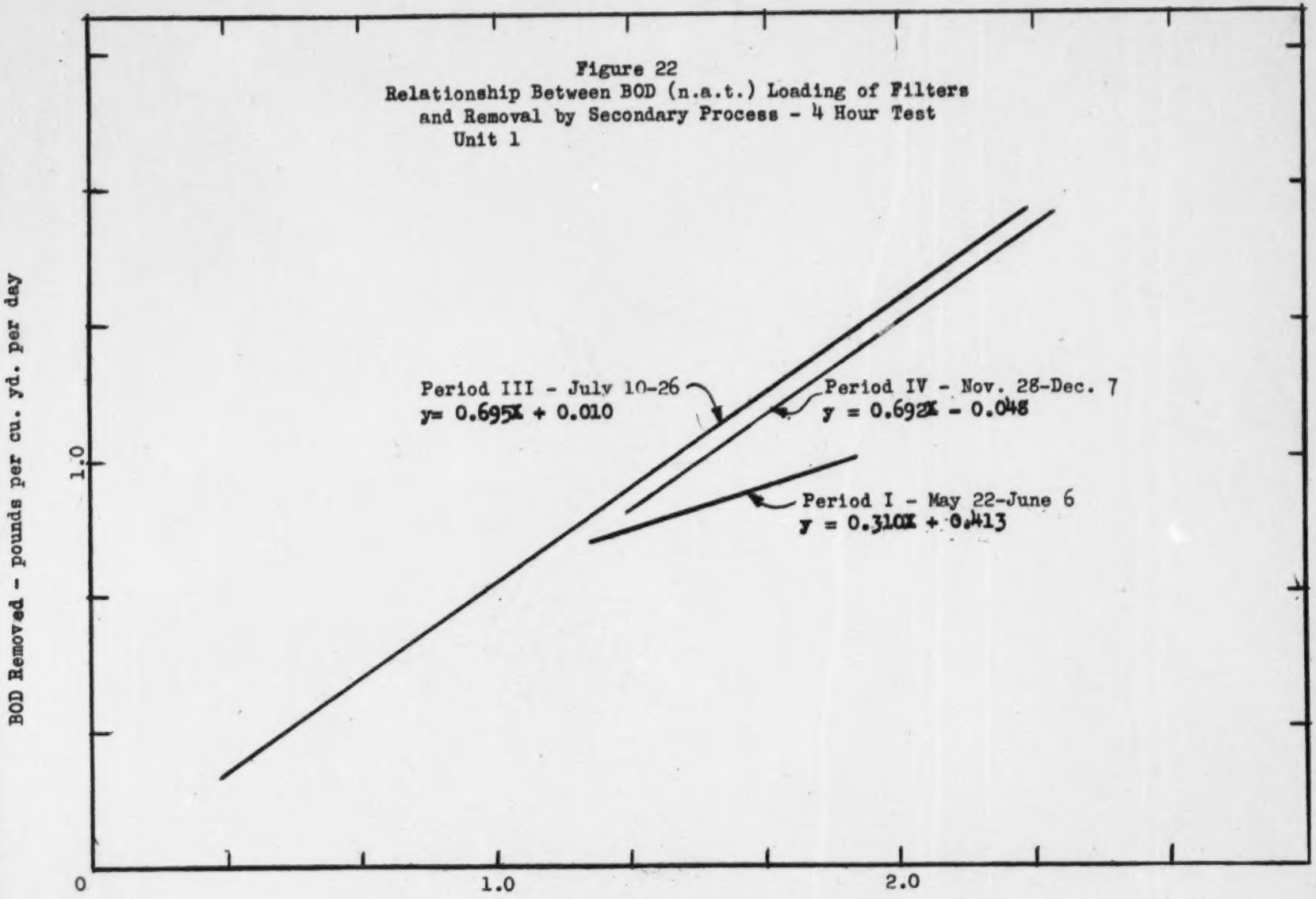
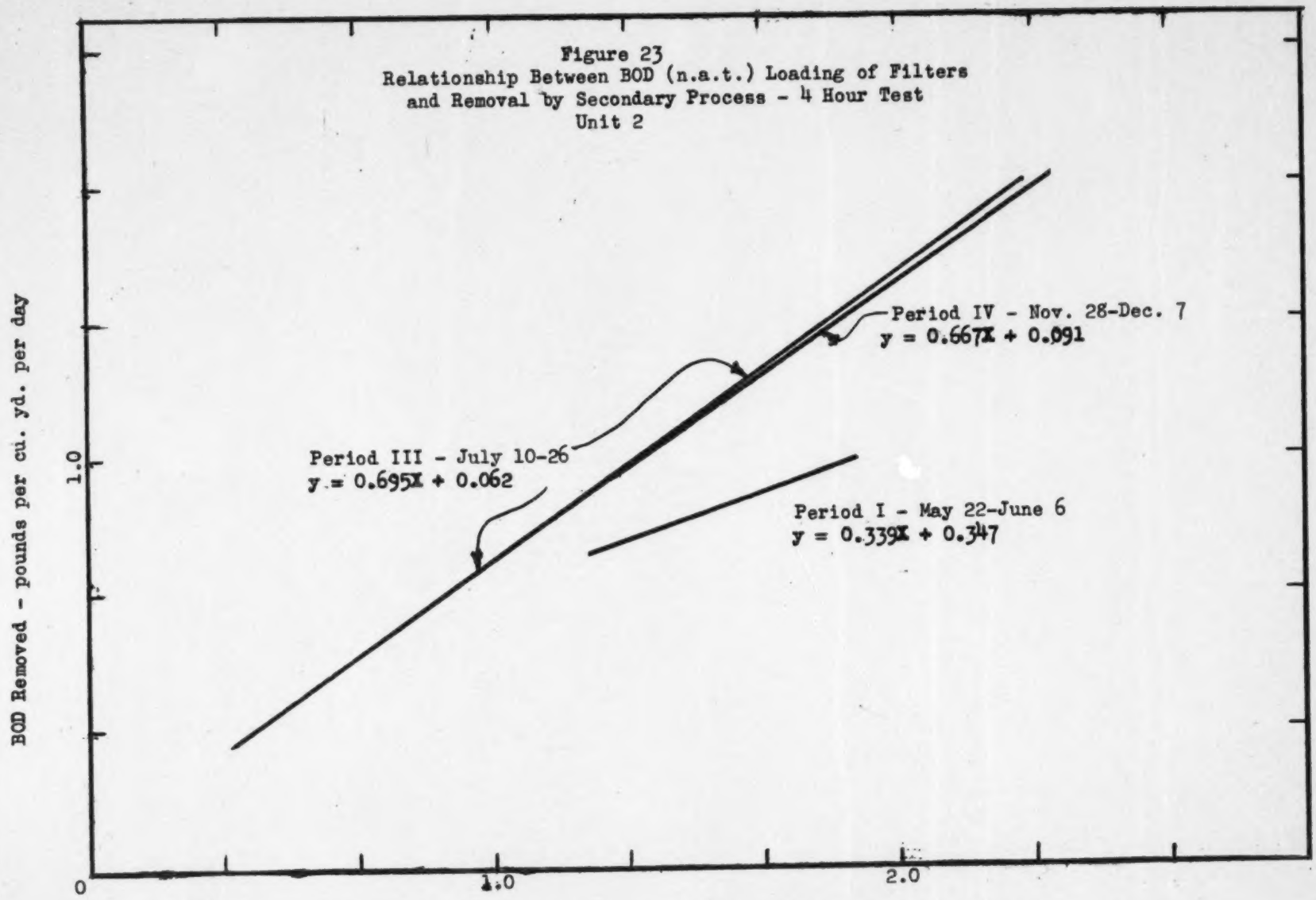

Period III - July 10-26
y= 0.695x + 0.010
Period IV - Nov. 28-Dec. 7
y = 0.692x - 0.048
Period I - May 22-June 6
y = 0.310x + 0.413
1.0
0
1.0
2.0
BOD Removed - pounds per cu. yd. per day
BOD Applied - pounds per cu. yd. per day (Settled Raw Sewage)

Figure 23
Relationship Between BOD (n.a.t.) Loading of Filters
and Removal by Secondary Process - 4 Hour Test
Unit 2


Period IV - Nov. 28-Dec. 7
y = 0.667x + 0.091
Period III - July 10-26
y = 0.695x + 0.062
Period I - May 22-June 6
y = 0.339x + 0.347
1.0
0
1.0
2.0
BOD Removed - pounds per cu. yd. per day
BOD Applied - pounds per cu. yd. per day (Settled Raw Sewage)

APPENDIX A

Biological Report

Biological Investigations of High Capacity Filters
Webster City, Iowa, Studies
May - November, 1950

John N. Wilson, Biologist

Summary and Conclusions

1. These investigations were made to furnish information on the biological characteristics of the filters and of their influents and effluents, as well as to provide detailed information on the populations and interrelations of their microbiota throughout the period of experimentation.

2. At the beginning of the experiment, both trickling filters contained heavy, black deposits of humus and putrescible matter. Filter No. 2, which later received direct recirculation, was particularly notable in this respect and showed incipient ponding. This was ascribed in part to the large amount of broken rock ("fines") within the bed.

3. Shortly after the direct recirculation was started on Filter No. 2, the filter began to slough or unload. It was at this time that filter flies, Psychoda sp., began to make their appearance. Filter No. 1 unloaded to some extent but continued to show a tendency to pond throughout the entire period of experimentation. Very few filter flies occurred in No. 1. By mid-July, No. 2 looked clean and open throughout, had no black slime in its upper strata and contained a thriving population of filter flies. These conditions prevailed through November.

4. The greenish-black, leathery growth which occurred on the upper surfaces of rocks and walls of both filters was most prevalent in late summer and early fall. This material was composed of several algal and bacterial organisms including Oscillatoria type, diatoms, zoogloea, Ulothrix sp. and Chlorella type. These organisms had all been found during colder weather on or near the surface of the filters, but in response to the increased nutrients with recirculation, the warm weather and sunlight, they grew rapidly to produce those conspicuous, leathery patches. Their presence is beneficial to the treatment as long as they do not clog the filter.

5. In November, Filter No. 1 still showed incipient ponding at 8 out of 12 places which were probed; however, the other places showed the effect of sloughing and scouring of the rocks. This was apparently caused by the activity of increasing numbers of filter

flies. At that time, Filter No. 2 was still open and clean-looking. Flies were abundant in all stages of development and there were no deposits of black humus or putrescible material found.

6. The volume of solids per unit weight of rock was consistently lower in Filter No. 2 than in Filter No. 1, except in June.

7. The organisms are classified into binding, free-living and scouring groups, on the basis of their function and characteristics. Filter No. 1 contained larger concentrations of binding organisms than No. 2 in all but the sample for May and June. Free-living forms were more abundant in Filter No. 2, however, until November when No.1 exceeded No. 2. The population of scourers (Nematodes, Rotifers and Psychoda) increased in both filters as the experiment progressed, with No. 2 showing consistently higher concentrations of these forms. In November, there were about 5 times as many scourers in Filter No. 2 as in No. 1. These organisms were responsible in some degree for the clean appearance of this filter and for freedom from ponding.

8. The increased loading on both of the filters caused increases in concentrations of visible bacteria. These increases were usually accompanied by increases in numbers of protozoan bacterial feeders. In November, numbers of these visible bacteria in Filter No. 1 attained to 107 million per ml., as compared to 84 million in No. 2. This is attributed to the semiclogged condition of No. 1.

9. As Filter No. 2 unloaded in July, numerous stalked ciliate protozoans (Epistylis sp.) appeared for the first time along with Aspidisca sp. Both of these forms are indicative of open, well-aerated filters. In contrast, certain protozoans such as Metopus sp. and Hexamitus inflatus, which are commonly found in anaerobic or putrid situations (Imhoff tanks), were often found in No. 1.

10. In general, the results from the influent and effluent samples which were collected immediately after stoppage of the distributor corroborated those from the upper filter strata.

Description of Study

These biological investigations were made to determine the effects of the direct recirculation of trickling filter effluent on the microbiota of the filter. Particular attention was directed toward the expected accumulation of solids in the filter, and comparisons were made between the experimental filter having direct recirculation (Filter No. 2) and a control filter (Filter No. 1) through which was recirculated effluent from the final clarifier. In co-operation with

the mobile units of the Survey and Investigation Branch, four biological examinations of the filters were made during the periods of May 24-27, June 10-15, July 15-19 and November 22-26, 1950.

General features of the sewage treatment plant were described in the engineering and chemical sections of this report. However, some characteristics of the filters are included herein.

The two circular filters are 40 feet in diameter and about 7.5 feet deep. The media is crushed pink granite with the following specifications:

Passing 3-1/2 inch screen	100%
Retained on 3 inch screen	0 - 5%
Retained on 2-1/2 inch screen	50%
Passing a 1-1/2 inch screen	0 - 3%
Passing a 1 inch screen	0%
Soundness (sodium sulphate test)	
Number of cycles	20
Material retained on 1 inch screen at end of test	85%
Material retained on 1/2 inch screen at end of test	95%

The rock was graded before shipment and no particular care was used in handling or placement. Some large rock, probably in excess of 3-1/2", was noted on the filter surface, and fine particles accumulated in the underdrains. The "fines" were particularly in evidence in Filter No. 2.

Observations, Methods and Analyses

General Observations

The first biological examinations (May 24-27) were made almost two weeks before the experimental recirculation procedure was started. At that time, Filter No. 2 showed much more incipient ponding than Filter No. 1. This was attributed to the larger amount of fine stone in Filter No. 2 than in No. 1. Both filters, however, contained extensive deposits of black, humus-like material along with sulphur salts and putrescible matter. Most of the rocks which were collected for samples were coated with the black sulphide deposits. This material adhered tenaciously despite vigorous scrubbing with a scrub brush.

The investigation in June was made three days after the experimental recirculation was started. Observations and tests made at this time are combined with the results from May, and together they are considered as base-line studies. Results of the chemical tests show, however, that a "leveling off" or rather a condition of near equality of performance was reached by the filters during the first week in July.

Filter flies (Psychoda sp.) started to make an appearance in both filters in June. Filter No. 1 had a sparse population but Filter No. 2 was well on its way toward a bumper fly crop by June 10.

The most noticeable change in Filter No. 2 (direct recirculation) occurred in the interval between June 10 and July 15. The incipient ponding noted in June was no longer in evidence. On the contrary, the black, putrescible and humus-like material had entirely disappeared and, in its place, there was the brownish-gray slime (zoogloea primarily) on all rock surfaces which is characteristic of efficient filters and is the major component of activated sludge. At the same time, Filter No. 1 still showed a tendency to pond, for there were extensive black deposits in the bed.

Beginning the latter part of July and continuing through the unusually warm fall, there were heavy blackish green, nodular growths on the upper surfaces of both filters. These growths were reported to be particularly heavy in those portions of Filter No. 2 which were continually shaded by the wall of the filter. These growths were largely blue-green algae (Oscillatoria type, probably Phormidium), but mingled with these blue-green algae there were also some zoogloea, Chlorella type, Navicula and Ulothrix (a green alga).

The plant operator collected several samples in August and September, preserved them and shipped them to this laboratory with the results of determinations for settleable solids which were made at the plant. Because of changes and distortion of the organisms by the formaldehyde, the microscopic examinations were unsuccessful and, therefore, have not been included in this report. However, the results of the tests for settleable solids have been used to advantage.

In November, Filter No. 2, which had been operating five months with direct recirculation, appeared to be in excellent condition. The investigator probed into the bed at eight points and found no evidence of ponding. Psychoda were abundant in all stages of development, but they were under control because of the cold weather and heavy flow.

By contrast, Filter No. 1 showed a tendency to pond in eight out of twelve places which were probed. However, there was some indication of an increasing fly population in places where their scouring action induced sloughing and cleaning of the filter.

Methods and Techniques - Collection of Samples

Samples of filter effluent were collected from the collection trough in the filter gallery, and influent samples were obtained from distributor nozzles. Rocks from the filter surface extending down to a depth of 18 inches to 2 feet were removed and placed in influent sewage in photographic pans and held for examination. The timing for collection of samples of effluent and filter growth was an important consideration because, when the distributor was stopped, the concentration of solids in the effluent increased to a remarkable degree. This was attributed to the flushing action of the static distributor on limited areas of the filter. The sequence of samples taken was as follows:

1. Effluent before stoppage of distributor
2. Effluent after stoppage of distributor
3. Influent
4. Rock samples.

The effluent and influent samples were tested for settleable solids in Imhoff cones and about 500 ml. of additional material was refrigerated. Growth from the rocks was removed by means of a scrub brush and dispersed in the sewage in the pans. The samples were stirred individually and poured into one-liter graduate cylinders to test for settleable solids. The remainder of each sample was measured to determine the total volume of the mixture. Samples for microscopic examination were obtained from this portion and were examined in the living state within 8 hours. Readings of settled matter were made at one and two-hour intervals. The scrubbed rocks were later weighed.

The samples of concentrated growth from the rocks were examined by the Lackey drop method ("The Manipulation and Counting of River Plankton and Changes in Some Organisms due to Formalin Preservation." Lackey, James B., Public Health Reports 53, 2080-2093. Nov. 25, 1938), using pipettes calibrated to 20 drops per milliliter. For microscopic examination, 22-mm. square cover glasses were used on plain glass slides with one drop per slide. Kinds and numbers of organisms were determined using the crisscross and random selection methods. Numbers of organisms were reported per ml. of settled matter and converted to number per pound of filter rock.

As the influent and effluent samples contained much less growth and humus matter to obstruct vision, they were enumerated in a standard plankton-counting cell (Sedgwick-Rafter). Numbers of organisms were recorded per milliliter of sample.

Results of Analyses

Reference is made to the method used to determine roughly the volume of solids in the filters per unit of rock weight. The results are shown in Figure 1. As indicated in this graph, the volume of solids was consistently lower in Filter No. 2 (direct recirculation) than in Filter No. 1 (except June). This was particularly noticeable in July, when the volume on No. 2 was less than half that on No. 1. The data for November fail to show the marked difference which was indicated by observation. Filter No. 1 ranged from an over-all high of 71 ml. per pound of rock in May to 16 ml. in October, while Filter No. 2 ranged from 47 ml. in June to 11 ml. in October.

Quantitative microscopic examinations of the growth from the upper strata (2 ft.) of the filters were made on 22 samples. The organisms represented in these counts have been classified into "binding," "free-living" and "scouring" groups (Figures 2, 3, 4). Filter No. 1 contained a predominance of binding forms (zoogloea, fungi, sphaerotilus, etc.) in all but the samples for May and June. Free-living organisms (protozoa, green flagellates, etc.), however, were more abundant in No. 2 until November when numerous diatoms (Navicula spp.), colorless flagellates (Anisonema sp.) and green flagellates appeared in Filter No. 1, causing its free-living population to exceed that found in Filter No. 2.

The populations of scouring organisms (Rotifers, Nematodes and Psychoda) increased in both filters as the experimental period progressed, with No. 2 filter indicating consistently higher concentrations of these forms. In November, in No. 2 filter, there were nearly one-half million per pound of rock in comparison to less than 100,000 in No. 1. These scouring or grazing organisms in No. 2 contributed in no small measure to the clean appearance of the filter and the freedom from ponding.

Accompanying the scouring by organisms and natural sloughing in No. 2, there was a considerable number of stalked ciliate protozoans such as Epistylis sp. These are indicative of an open, well-aerated filter. No. 1 contained only traces of these organisms and, in contrast to No. 2, there were some colorless flagellates found in No. 1, such as Hexamitus inflatus. The latter are facultative anaerobes common in such places as Imhoff and septic tanks.

Trends were also observed in the so-called "background" or visible bacteria in comparison to the bacteria feeders (mostly ciliate protozoa) (Figure 5). Both filters experienced increases in numbers of these visible bacteria which, in No. 1, were accompanied by an increase in numbers of the bacteria feeders. In No. 2, however, there was a high peak in the population of bacteria feeders in July, followed by a sharp decline in November. The large numbers in July are attributed to the influx of stalked ciliate protozoa and the small amoeba, Hartmanella sp.

Some of the organisms which occurred most consistently in the upper strata of the filters are presented in Table 1, with their frequency of occurrence. Comparison is made between Filters 1 and 2.

Zoogloeal bacteria are invariably to be found in sewage filters. Such also is usually the case with Sphaerotilus sp. and white sulphur bacteria, Beggiatoa alba. Blue-green and green algae occurred in greatest numbers in late summer and fall. The rhizopod protozoa (Amoeba spp., Pelomyxa, Hartmanella, etc.) were not found in November. Aspidisca sp., a small ciliate which is indicative of an efficient, well aerated filter, was found consistently in the July and November samples of No. 2, but in No. 1, Aspidisca was found only in November. The ciliate, Metopus sp., a common inhabitant of Imhoff tanks and other poorly aerated situations, was collected in only 3 out of 13 samples from No. 2 but was found in 7 of 9 in No. 1.

The results of the influent and effluent samples are plotted in Figures 6 and 7. These are based on 9 influent and 28 effluent samples. Filter No. 1 showed a decrease in binding and scouring organisms over the period of study, but the free-living organisms increased. The number of organisms in the influent ranged around 5% of the number in the effluent.

In Filter No. 2, the binding organisms showed a very marked decrease during the first month of direct recirculation, but in the following four months to the end of November they increased to about two-thirds of the original population. In direct contrast to the binding organisms, the free-living and scouring forms showed tremendous increases during the first month, followed by an appreciable decrease by November.

During the entire study, many times as many free-living organisms were found in Filter 2 influent as in the influent of Filter 1. This difference was particularly marked in July, and might be attributable to the effects of direct recirculation.

Table 1. Percentage Frequency of Occurrence of Organisms

	Per Cent Frequency	
	Filter #1	Filter #2
Binding Organisms		
Zoogloea	100	100
Beggiatoa	89	100
Sphaerotilus	100	100
Spirillum	67	85
Oscillatoria type	33	38
Chlorella type	100	62
Scouring Organisms		
Nematodes	100	92
Rotifers	78	62
Psychoda	22	54
Free-Living Organisms		
Navicula	78	38
Hexamitus inflatus	56	8
Amoeba	56	38
Aspidisca	22	38
Colpoda	56	54
Epistylis	22	46
Lionotus	33	46
Metopus	78	23
Paramecium	78	100
Vorticella	67	69

Figure 2

Volume of Settleable Solids per Pound of Rock in the Filters

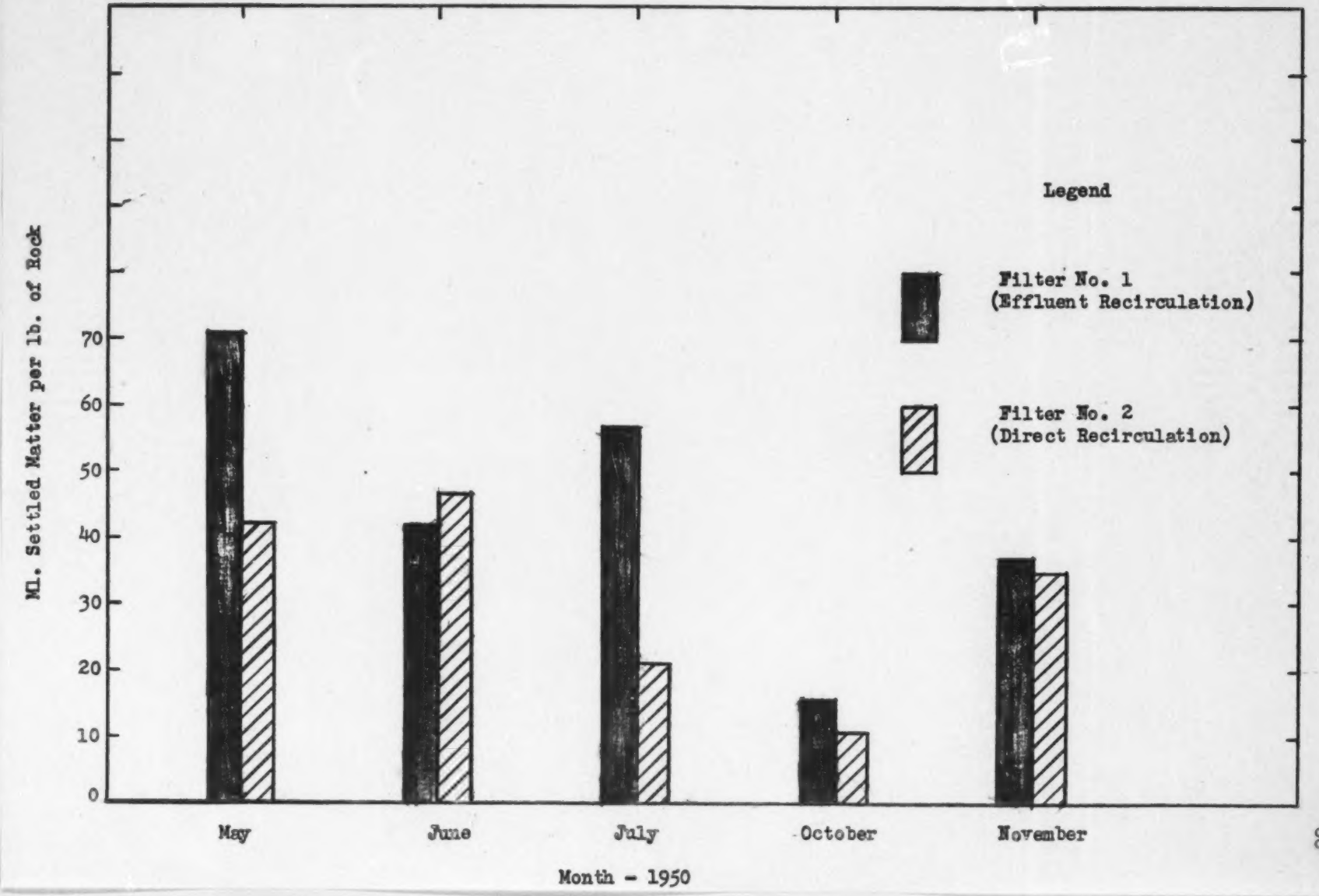
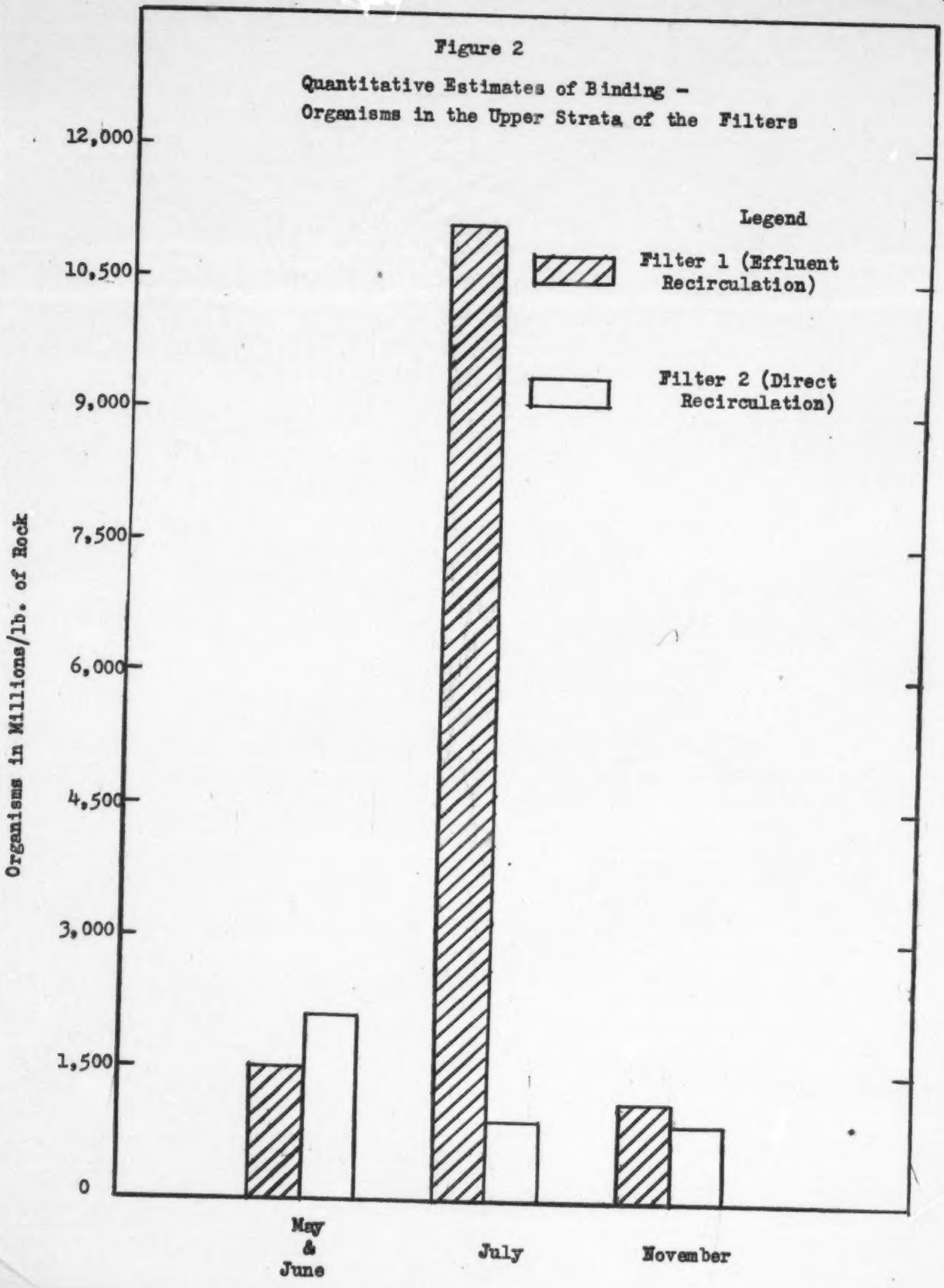


Figure 2

Quantitative Estimates of Binding -
Organisms in the Upper Strata of the Filters



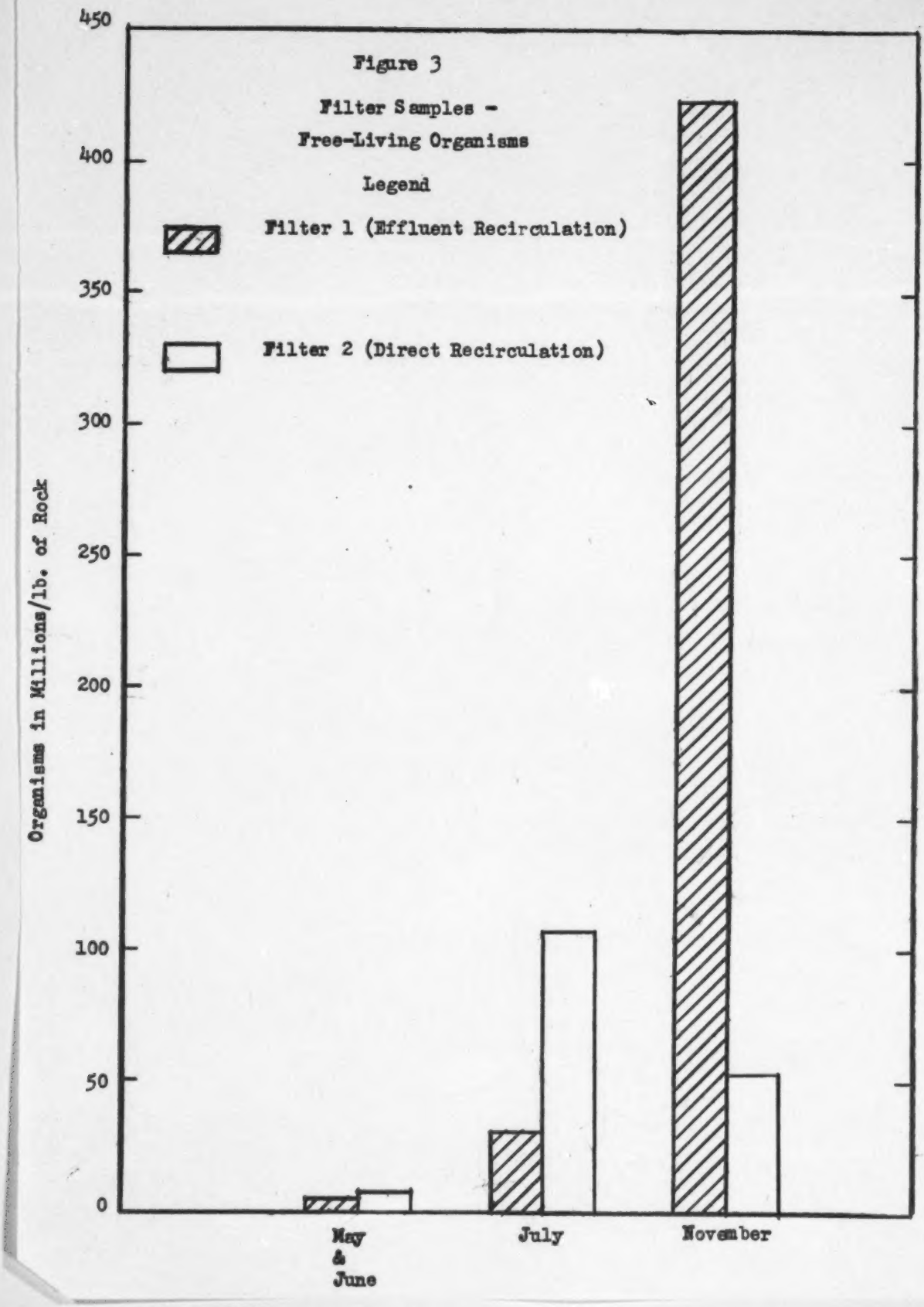


Figure 3
Filter Samples -
Free-Living Organisms
Legend
Filter 1 (Effluent Recirculation)
Filter 2 (Direct Recirculation)
Organisms in Millions/lb. of Rock
450
400
350
300
250
200
150
100
50
0
May & June
July
November

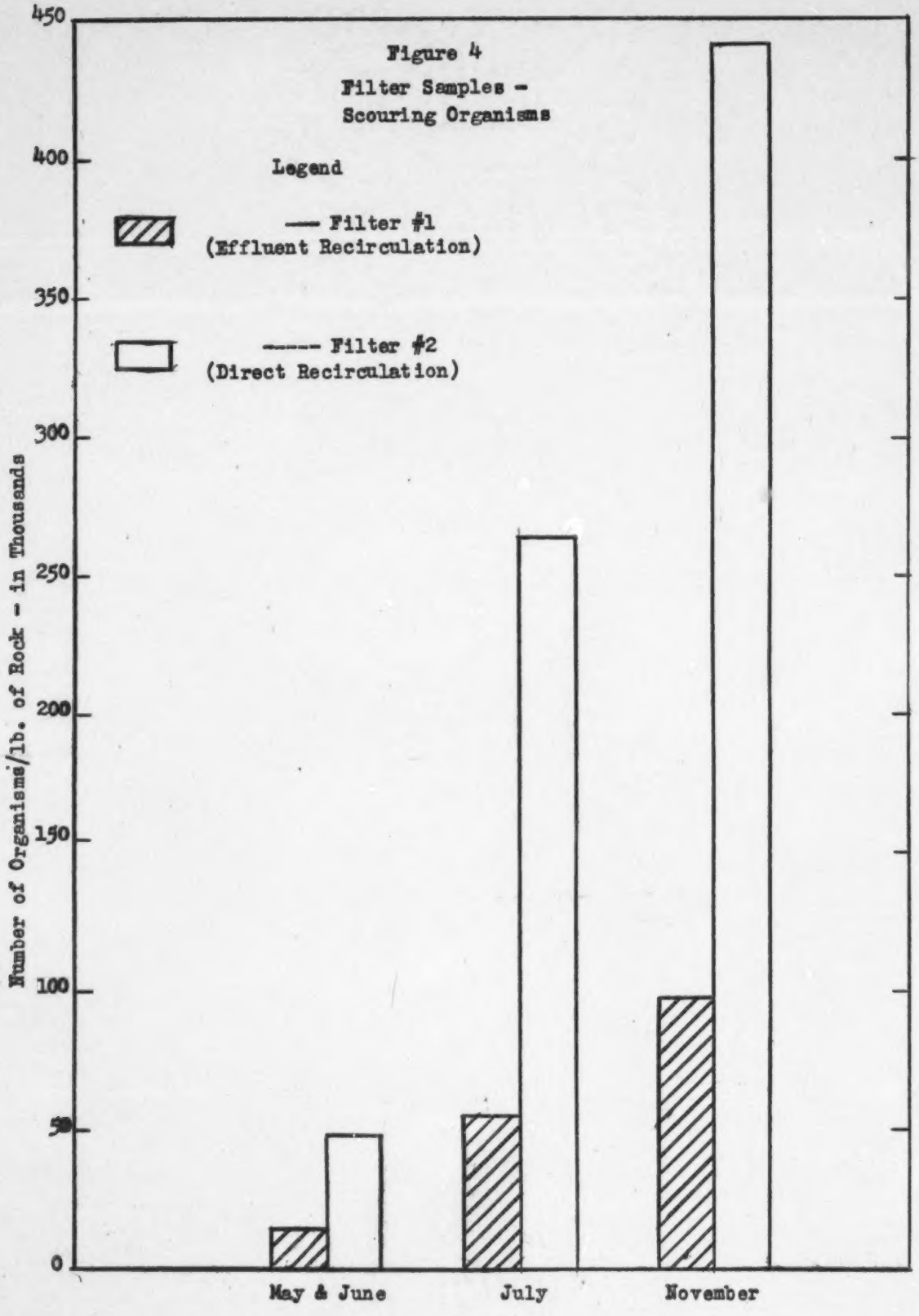
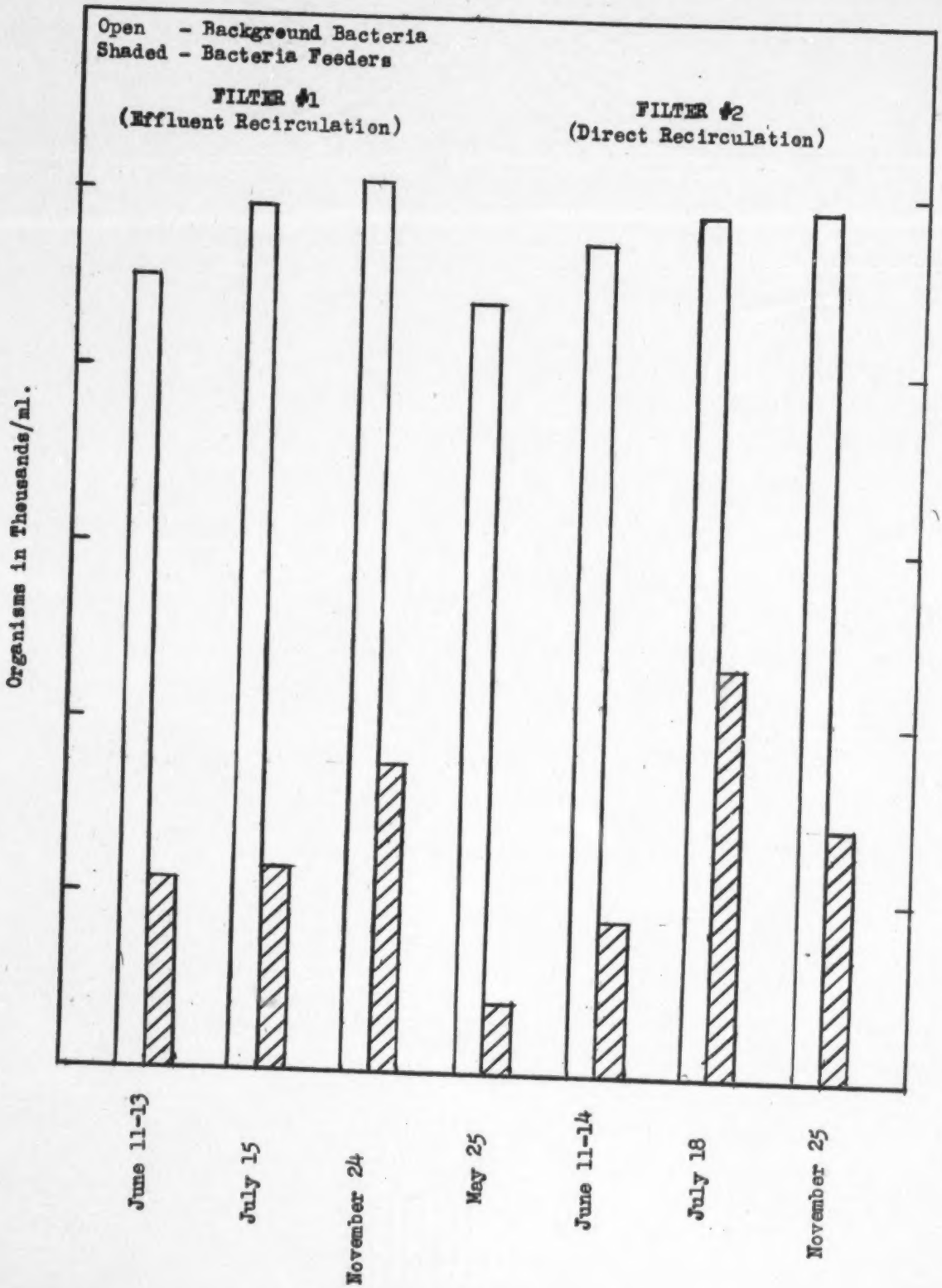


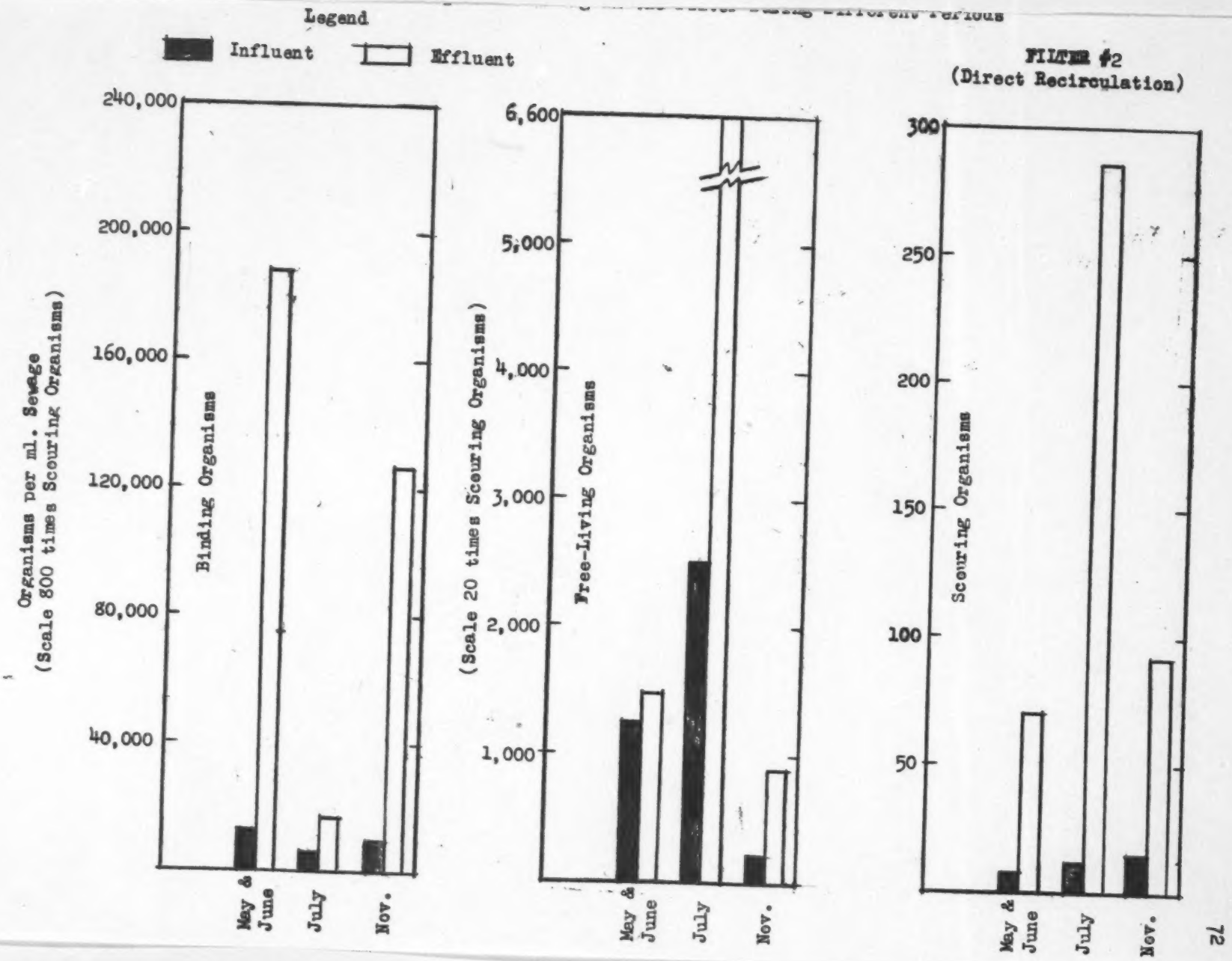
Figure 4
Filter Samples -
Scouring Organisms
Legend
— Filter #1
(Effluent Recirculation)
----- Filter #2
(Direct Recirculation)
Number of Organisms/lb. of Rock - in Thousands
450
400
350
300
250
200
150
100
50
0
May & June
July
November

Figure 5

Relation of Background Bacteria to Bacteria Feeders



FILTER #1
(Effluent Recirculation)
Legend
Influent
Effluent
Organisms per ml. Sewage
(Scale 800 times Scouring Organisms)
120,000
100,000
80,000
60,000
40,000
20,000
Binding Organisms
May & June
July
Nov.
(Scale 20 times Scouring Organisms)
2500
2000
1500
1000
500
Free-Living Organisms
May & June
July
Nov.
125
100
75
50
25
Scouring Organisms
May & June
July
Nov.


Legend
Influent
Effluent
FILTER #2
(Direct Recirculation)
Organisms per ml. Sewage
(Scale 800 times Scouring Organisms)
Binding Organisms
240,000
200,000
160,000
120,000
80,000
40,000
(Scale 20 times Scouring Organisms)
Free-Living Organisms
6,600
5,000
4,000
3,000
2,000
1,000
Scouring Organisms
300
250
200
150
100
50
May & June
July
Nov.

APPENDIX B

Formulae

Flow measurements were made and samples were collected as listed below. The locations of these flow-measuring devices and sample points are shown on the flow diagram appearing on the following page, and are as follows:

Flow Measurements

a (Venturi meter)

m (orifice)

n (orifice)

t (pump calibration)

Sample Points

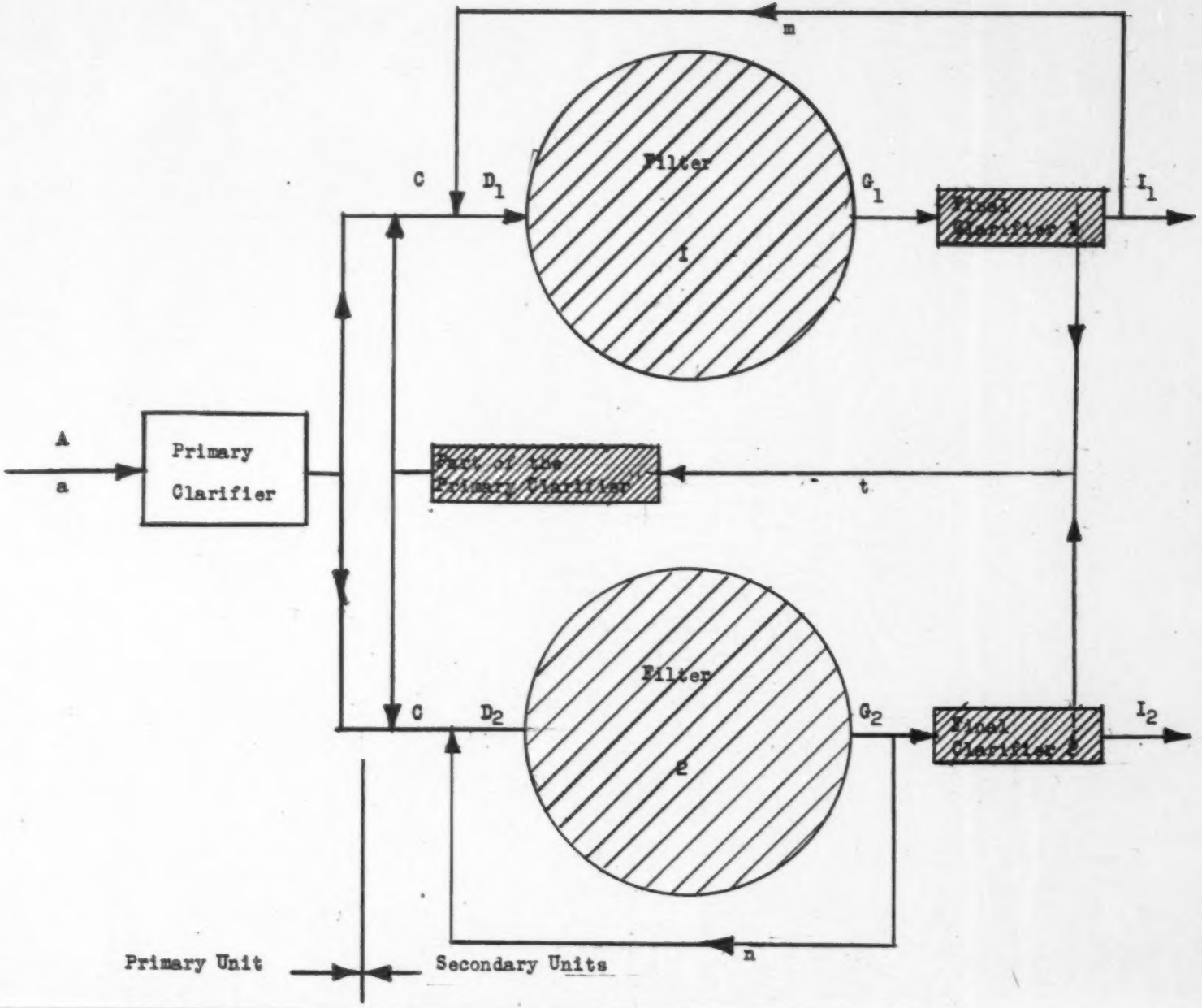
A

C

D_1 - D_2

G_1 - G_2

I_1 - I_2



Flow Diagram

NOMENCLATURE

A, C, D, G, I, T*	Concentrations in p.p.m.
a, c, d, m, n, t	Flows in M.G.D.
L, E, R	Pollutant material in pounds per day
K	A constant = 8.34 = $\frac{\text{lbs/day}}{\text{MGD x ppm}}$

ASSUMPTIONS

$C = C_1 = C_2$ (Effluent from primary clarifier equally divided)

$T_1 \geq I_1$ (Limiting value)

$T_2 \geq I_2$ (Limiting value)

$$T \geq \frac{I_1 + I_2}{2}$$

$C_1 = C_2 = \frac{a+t}{2}$ (Effluent from primary clarifier equally divided)

$t_1 = t_2 = \frac{t}{2}$ (Equal underflow from secondary clarifiers)

FORMULAE

Flows:

To Treatment Plant a

To Primary Process a

To Secondary Processes

Unit 1 $c_1 - \frac{t}{2} = \frac{a}{2}$

Unit 2 $c_2 - \frac{t}{2} = \frac{a}{2}$

* Impossible to sample this flow. Concentration was assumed.

To Filters

Unit 1 $d_1 = c_1 + m = \frac{a+t}{2} + m$

Unit 2 $d_2 = c_2 + n = \frac{a+t}{2} + n$

Effluent

Unit 1 $\frac{a}{2}$

Unit 2 $\frac{a}{2}$

LOADINGS

Treatment Plant (L_t) $a\,AK$

Primary Process (L_p) $a\,AK$

Secondary Processes

Unit 1 (L_{s1}) $\left[\left(\frac{a+t}{2}\right) C - \frac{t\,(I_1 + I_2)}{4} \right] K$

Unit 2 (L_{s2}) Ditto

Filters

Unit 1 (L_{f1}) $\left(\frac{a+t}{2} + m\right) D_1 K$

Unit 2 (L_{f2}) $\left(\frac{a+t}{2} + n\right) D_2 K$

Effluent

Unit 1 (E_1) $\frac{a}{2} I_1 K$

Unit 2 (E_2) $\frac{a}{2} I_2 K$

REMOVALS

Treatment Plant (R_t) $a \left[A - \left(\frac{I_1 + I_2}{2}\right) \right] K$

Primary Process (R_p) $\left[aA - (a+t) C + \frac{t\,(I_1 + I_2)}{2} \right] K$

Note: Residual BOD in Settled Sewage (%) $\dfrac{(a+t) C - t \left(\frac{I_1 + I_2}{2}\right)}{aA} \times 100$

Secondary Processes

Unit 1 (R_{s1}) $\quad L_{s1} - \frac{a}{2} I_1 K$

Unit 2 (R_{s2}) $\quad L_{s2} - \frac{a}{2} I_2 K$

PER CENT REMOVALS (Efficiency based on plant loading)

Treatment Plant $\quad \frac{R_t}{L_t} \times 100$

Primary Process $\quad \frac{R_p}{L_t} \times 100$

Secondary Processes

Unit 1 $\quad \frac{R_{s1}}{(\frac{L_t}{2})} \times 100$

Unit 2 $\quad \frac{R_{s2}}{(\frac{L_t}{2})} \times 100$

PER CENT EFFICIENCY (Based on unit loading)

Treatment Plant $\quad \frac{R_t}{L_t} \times 100$

Primary Process $\quad \frac{R_p}{L_p} \times 100 = \frac{R_p}{L_t} \times 100$

Secondary Processes

Unit 1 $\quad \frac{R_{s1}}{L_{s1}} \times 100$

Unit 2 $\quad \frac{R_{s2}}{L_{s2}} \times 100$

The above formulae are essentially the same as used in "Sewage Treatment at Military Installations," (SWJ 18, 791-1028, Sept., 1946).